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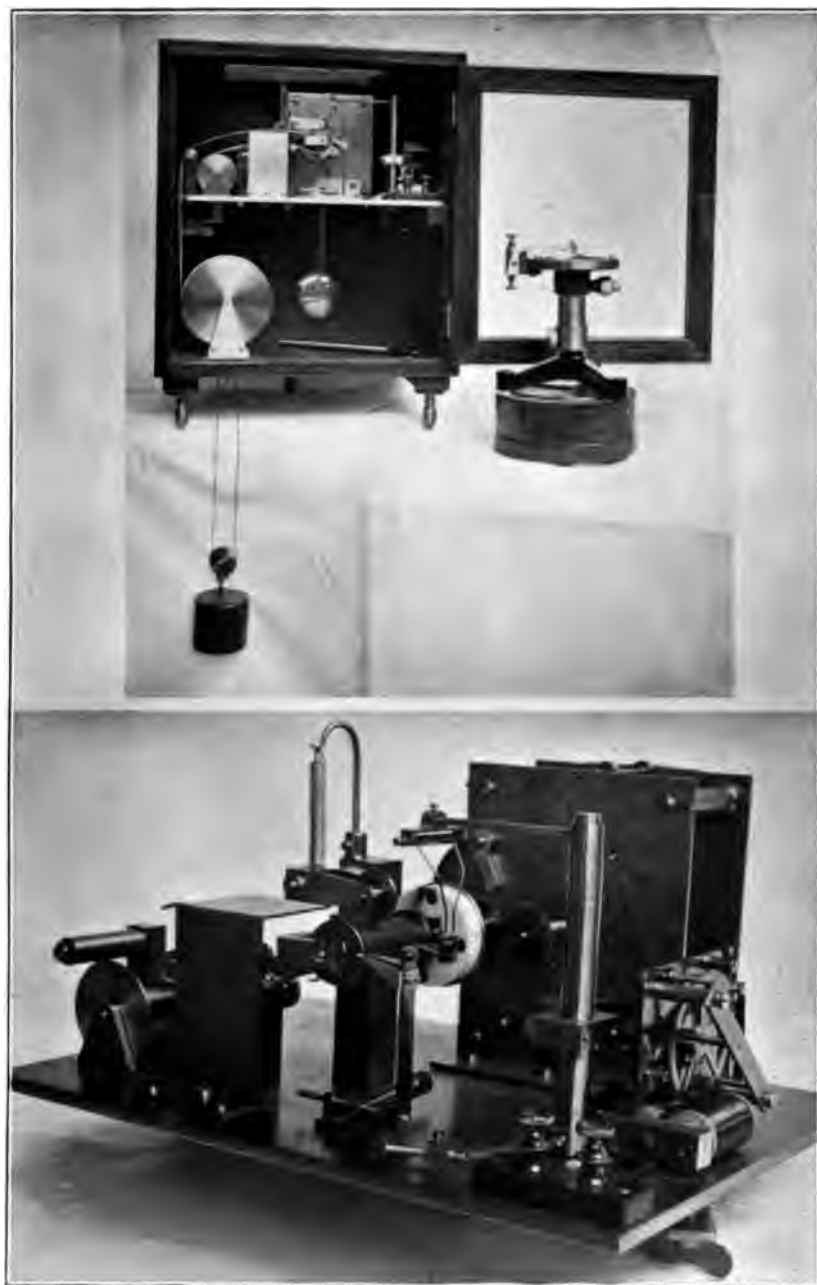
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NO. 1

EARTHQUAKES AND STRUCTURAL ENGINEERING

By J. C. BRANNER

Dr. J. C. Branner,
Stanford University, Cal.

Dear Sir:

The —— Company, of which I am the chief engineer, propose: to build several reservoir dams in the states of —— and —— . If the Seismological Society of America can give me or refer me to information about the frequency and character of the earthquakes in those states it will enable me to determine the types of structures indicated.

Thanking you for your help in this matter, I remain

Very truly yours,

— — —

This letter, from one of our best and most trustworthy engineers, brings home to us very sharply the need of the kind of information asked for. Our reply to it was necessarily short and disappointing, both to the engineer and to us. Some of the things that might have been said are given here for the sake of the cause and for the information of those who, sooner or later, are likely to ask similar questions.

To our great regret the reasonable information requested by this engineer cannot be furnished either by the Seismological Society or by any other organization, or by any individual, for the simple reason that it does not exist. And it does not exist because there has been and there still is no systematic collection and publication of earthquake data in this country.

As every engineer knows, the data called for cannot be obtained by experimental work in laboratories or deduced from mathematical formulas, but they require observations covering wide areas and long periods of time.

Inasmuch as earthquakes are matters that concern the public in a large sense, one naturally expects to find information regarding them

gathered and published by the scientific bureaus of the federal government; but up to the present time the federal government has not taken this matter seriously.

The earthquake of April 1906 shook California hard enough to awaken a wide and lively interest in earthquakes — on the west coast at least — and naturally enough the Seismological Society of America came into existence.

One of the chief objects of this society has been and is to gather and publish data in regard to earthquakes, and to use the data both for direct practical purposes and for the investigation of some of the larger problems of geology. But the collection of information on the west coast of North America in regard to earthquakes is not as simple and as easy as it looks at first glance. The difficulties are of several kinds, and are here briefly mentioned in order that engineers may know why the required data are not available, and in order that these difficulties may be overcome as soon and in so far as possible.

First, the frequency of light earthquake shocks on the west coast is, in itself, a difficulty, for the very reason that most people are accustomed to them, and there is therefore nothing either alarming or impressive about them, outside opinion to the contrary notwithstanding. It is a common experience to hear a remark like this in the middle of a conversation: "By the way, did you feel that earthquake last night?" and after a yes or no, the conversation goes on without further interruption. The general result of this attitude of mind is that most people think too little of the matter to formally report the time and intensity of the shock. It does not really seem to be worth while.

Another and more serious obstacle is the attitude of many persons, organizations, and commercial interests toward earthquakes in general. The idea back of this false position — for it is a false one — is that earthquakes are detrimental to the good repute of the west coast, and that they are likely to keep away business and capital, and therefore the less said about them the better. This theory has led to the deliberate suppression of news about earthquakes, and even of the simple mention of them. Shortly after the earthquake of April 1906 there was a general disposition that almost amounted to concerted action for the purpose of suppressing all mention of that catastrophe. When efforts were made by a few geologists to interest people and enterprises in the collection of information in regard to it, we were advised and even urged over and over again to gather no such in-

formation, and above all not to publish it. "Forget it," "the less said, the sooner mended," and "there hasn't been any earthquake" were the sentiments we heard on all sides.

There is no doubt about the charitable feelings and intentions of those who take this view of the matter, and there is a reasonable excuse for it in the popular but very erroneous idea prevalent in other parts of the country that earthquakes are all terrible affairs; but to people interested in science and accustomed to the methods of science, it is not necessary to say that such an attitude is not only false, but it is most unfortunate, inexcusable, untenable, and can only lead, sooner or later, to confusion and disaster.

The only way we know of to deal successfully with any natural phenomenon is to get acquainted with it, to find out all we can about it, and thus to meet it on its own grounds. That is the way mankind has succeeded thus far, and it is safe to conclude that it is the only way it ever will succeed.

In the first place, the great majority of earthquakes experienced on the Pacific coast are not dangerous in any sense whatever; while the suppression of information regarding them leads those who live elsewhere to the entirely natural but erroneous conclusion that they are all dangerous. The truth about the matter is therefore not to the disadvantage of the region concerned. On the other hand, if there are places so liable to destructive earthquakes that houses, dams, bridges, and other structures should not be built in them, or, if built, must be specially constructed with a view to withstanding earthquakes, then we think the people should know where those places are. If certain types of structures are dangerous, we think it ought to be known what they are. Certainly nothing is to be gained by shutting our eyes to genuine dangers or by exaggerating or encouraging others to exaggerate perfectly harmless shocks into serious dangers.

To meet the practical problems of earthquakes we must find out about them; and we certainly cannot find out about them if we are not informed, or if we are misled or misinformed. We are convinced, also, that the terrors that earthquakes have for mankind are largely attributable to our own ignorance. The more we know about them the less harm they can do us, and the less reason we shall have to fear them. So that, after all, we come down to this absolute necessity: in order to deal successfully with them, we must have trustworthy information in regard to the time, the place, and the character of earthquakes.

The next question is, how to get information about earthquakes. That the information should be most valuable, it should be gathered over as wide an area and over as long a period as possible. And to that end it is necessary that we take the matter seriously, that we get all the information we can, and every time we can, and that we keep up our observations right straight along, year in and year out, whether the earthquakes are big or little. The man who is not willing to report a shock unless it be one that knocks his house down and kills half of his neighbors, is not a man from whom we can expect much valuable cooperation. Observers are needed who do not require such a violent stimulus.

Everything we know about the gathering of data goes to show that we should have, scattered over as wide an area as possible, as many observers as possible who will report their observations, whether they seem to be important or not. The notes should be sent to some central office where they can be correlated and turned to account, just as the observers of the Weather Bureau, scattered all over the country, send their records to central stations where useful deductions can be drawn from them.

Obviously the Weather Bureau, with its excellent organization and its agents scattered over the entire national domain, is in a position to record and report promptly and fully upon earthquakes. But unfortunately the suggestion that these agents should be required to report on earthquakes has not thus far received the support of the federal congress. And if the federal government will not gather the necessary data and furnish this much needed information, then we must gather it ourselves as best we may.

Left to our own devices and our own too slender resources, there seems to be nothing for us to do but to appeal to our colleagues and to engineers and educated people generally for help in gathering and publishing such observations. If we can get this cooperation, we shall be able in time to answer intelligently such reasonable letters as the one at the head of this article. But we feel it to be our duty to urge upon these very engineers the great importance and necessity of their own cooperation. To the engineers all over the country, and especially to the engineers of the west coast, we say: "Help us and we shall gladly do all we can to help you. If you feel an earthquake, report the time, place, and intensity to the Seismological Society of America." Taken alone, single observations may not be of any great importance; but

taken in connection with a hundred other observations, they may be very important indeed. We feel that this matter is well worth while, and that it should therefore be taken seriously, not only by geologists and structural engineers, but by architects, by business men, by enterprises and corporations that use the services of engineers, and by all other educated people.

In the task we have set ourselves we need the cooperation of observers over a wide area. Without such cooperation the efforts we shall be able to make cannot be very effective. It is hoped, therefore, that every person who observes an earthquake at any time or in any place in America will send to the secretary of the society a note of the time of its occurrence and its intensity. These two points — the time and the intensity — are the most important. Anything additional will be helpful and welcome.

The Rossi-Forel scale of intensities will be kept standing in the BULLETIN, so that persons having occasion to report shocks may readily give the approximate intensity if they prefer to use that scale. But the use of a formal scale is not really necessary: anything that will give an idea of the violence of the shock will answer just as well.

As for the time, it is not expected that it will be given with absolute accuracy. Even if one has no clock or watch at hand when a shock is felt, he usually has some idea of the time of day. When nothing closer can be given, don't hesitate to make a guess and send it in for what it is worth.

Finally, no one needs apologize for any fact he sends in. To our requests for information about earthquakes we are frequently told apologetically that "I don't know anything about earthquakes." There is but one reply to be made to such remarks, and that is that "we know precious little about them ourselves; we are just now trying to find out, and we want your help."

THE SOUTH CAROLINA EARTHQUAKE OF JANUARY 1, 1913.

By STEPHEN TABER

The western portions of North and South Carolina and the adjoining parts of Georgia and Virginia were disturbed by an earthquake shock on the afternoon of January 1, 1913. It was felt over an elliptical area of approximately 43,000 square miles, the origin of the disturbance being in the southwestern portion of Union county, South Carolina, in the neighborhood of latitude $34^{\circ} 43' N.$ and longitude $81^{\circ} 44' W.$ About the epicenter the shock was severe enough to displace furniture, overthrow chimneys, and form cracks in a few brick and stone buildings. The maximum intensity was therefore a little above VIII of the Rossi-Forel scale.

The facts on which this paper is based were obtained from over three hundred different sources. Many lists of questions were sent out, and considerable information was obtained from the local newspapers in the area affected. Data were also furnished by the students of the University of South Carolina, most of whom were at their homes, scattered throughout the state, on the day the earthquake occurred. Shortly after the earthquake, while making geological investigations in Laurens, Abbeville, and Greenwood counties, the writer interviewed many residents in that section of the state.¹

The epicenter was located in the Piedmont plateau region, about seventy-five miles from its southern margin. The average elevation of the plateau in this vicinity is from 700 to 800 feet above sea level, while the larger streams have excavated their valleys to a depth of about 200 feet below the old peneplain. The country is gently rolling with broad, flat divides, and rather narrow valleys; the streams are

¹The writer is indebted to many for information and assistance courteously given; but especially to Dr. Harry Fielding Reid, Special Expert in Charge of Earthquake Records for the United States Geological Survey, who placed at his disposal many letters and newspaper clippings; and to Mr. Harry Geren, Section Director of the United States Weather Bureau, and Dr. Joseph Hyde Pratt, State Geologist of North Carolina, both of whom gave valuable aid in the collection of data.

swift with occasional rapids, and the larger ones have intrenched meanders. The rocks of the area are all highly crystalline, consisting for the most part of quartz-mica schists, gneisses, some massive granites, and a few dikes of diabase. They nearly all dip at steep angles, usually toward the southeast, and the prevailing strike is in a northeast-southwest direction. Most of the rocks are decomposed to a considerable depth below the surface, so that hard rock exposures are rare except in the larger valleys.

The time of the shock, as given by the majority of the reports received, is only approximate, most observers simply stating that it occurred about 1:30 or about 1:25 p.m. Five reliable reports, however, from towns in the vicinity of the origin give the time as 1:27, and three others give it as 1:28. The nearest seismographs that recorded the shock are located at Washington, D. C. and Cheltenham, Md., both about 388 miles from the origin. The beginning of the preliminary tremors on the Washington record could not be accurately determined, but the long waves began at 1:29:59. According to the report from Cheltenham, the long waves began there at 1:30:05. Taking the mean of these determinations and assuming that the velocity of propagation of the long waves was 2.2 miles per second, the time of the shock would be 1:27:28 E. S. T., which is in close agreement with the best observations in the vicinity of the epicenter.

Descriptions of the shock agree in stating that it began without preliminary disturbance, except a roaring noise, rapidly increased to a maximum of intensity near the middle, and then died down a few seconds later; the duration of the shock as estimated by most observers was less than ten seconds, and probably not more than five or six. An observer in Chester reported two maxima separated by three or four seconds, and a newspaper account from the same place mentions a second shock at 2 p.m., but neither of these statements was verified by the other reports from that section. Only a few observers could give any information concerning the direction of vibration, and there was little uniformity in their testimony.

Sounds, other than the rattling of windows, china, and similar loose objects were reported by forty-four observers and nine of these stated that the noise preceded the shock. The sounds were almost uniformly reported from sections where the intensity was highest; few observers noticed any noise where the intensity was less than IV;

and only five reports from points outside of isoseismal III mention a low rumbling. The noise was usually described as a rumbling or roaring and was frequently likened to the sound of distant thunder or distant blasting; others compared it with the noise of a locomotive, roller-skates on a board walk, a rushing wind, or a fire. Some men who were out hunting near Enoree in Spartanburg county did not feel the shock, but heard a slight noise which they describe as similar to that made by a covey of birds in flight.

Several observers mentioned the behavior of animals during the earthquake. At three places, having intensities of IV, V, and VI respectively, chickens were seen to run to shelter. A peculiar case was reported from Hendersonville, Henderson county, N. C., where several panes of glass in a house on the outskirts of the town were broken by a covey of quail seeking shelter. Several of the quail broke through and were captured by the occupants of the house. A few people were slightly nauseated by the earthquake, but whether because of the motion or because of fright is not known.

The intensities at different localities, as measured by the Rossi-Foré scale, are indicated on the accompanying map by means of Roman numerals, and isoseismals are drawn to show their approximate distribution. All estimates of intensity were made by the writer, chiefly from the answers received to the lists of graded questions sent out. Most of the intensities agree with those at neighboring points and conform to the isoseismals drawn, while those that do not may, for the most part, be explained by the insufficient data on which some of the estimates were made. In a few instances abnormal intensities may be due to local conditions, such as variations in the geologic structure. Because of lack of space some of the figures indicating intensity had to be omitted from the map.

The shock was most severe in the southwestern part of Union county, South Carolina, where the intensity was a little above VIII. In passing away from the origin the decrease in the intensity was most rapid in northwest and southeast directions, and slowest in a northeasterly direction. The details in regard to intensity will be given for only a few of the more important points.

Isoseismal VIII encloses a roughly circular area about twelve miles in diameter, with Union, a town of 6,000 inhabitants, lying near the western border. At Union cracks were formed in the stone walls

of the jail, a building erected in 1823, and, to the terror of the prisoners, considerable plaster fell; cracks also appeared in the new brick court house, and in the court room the plastering was seriously damaged. Chimneys were thrown down in all parts of town, vases and other ornaments were overturned, plaster fell in many residences, and everybody rushed into the streets. The vibrations are said to have been in a northwest and southeast direction, and the earthquake was accompanied by a loud roaring noise. At Monarch, a mile and a half south of Union court house, a house was partly shaken down.

At Colerain, nine miles west of Union, the shock was reported to be more severe, but as most of the houses are of frame construction, little damage was done except to chimneys.



Isoseismals of the South Carolina Earthquake of January 1, 1913.
Rossi-Forel Scale.

A report from West Springs, near the county line, eleven miles northwest of Union, states that a rumbling noise like distant thunder preceded the shock by two or three seconds and continued until after it was over. The vibrations were northeast and southwest, and were of sufficient intensity to destroy some chimneys totally and to damage others. The only loss of life that was reported occurred at this point, a pig being killed by bricks from a falling chimney. A slight shock was felt in this vicinity on December 7, 1912, at 2:10 p.m., but resulted in no damage. According to a newspaper account printed at the time, there were two distinct shocks, which were of sufficient severity to cause many people to rush out of doors.

At Crosskeys, population 120, which is located about eleven miles southwest of Union, several chimneys were thrown down and other damage was done.

Spartanburg, having a population of about 18,000, lies twenty miles northwest of the supposed place of origin and just within isoseismal VII. Here the shock began with a noise similar to the roaring of a fire, or the escape of steam from a locomotive; but as the intensity increased dishes rattled, goods fell from the shelves in the stores, and many people ran into the streets; several chimneys were damaged, and a few pieces of glassware were broken. At Enoree, Pacolet, and Pauline, in Spartanburg county, and also at Gaffney, population 5,000, a few chimneys fell, but this seems to have been the extent of the actual damage in these places.

From the region between the isoseismals VI and VII little damage was reported beyond the breaking of some glass and china and the overthrow of a chimney at Kings Mountain. The shock caused some fright, and a few people left buildings; water was spilled from glasses, and tables and other furniture are said to have moved slightly. Nearly all observers report a roaring noise.

The shock was felt by practically everyone within the isoseismal V, while between isoseismals IV and V it was felt generally indoors, and by only a few who were out of doors. Outside of isoseismal III the shock was felt by comparatively few who were not indoors and at rest.

Isoseismal II, within which the earthquake was perceptible to the senses, encloses an area of approximately 43,000 square miles; outside of this area the shock was recorded only by seismographs and other delicate instruments. At Columbia, sixty-three miles southwest of the

origin and on the edge of the Coastal Plain sediments, the disturbance was noted by comparatively few people. At Lexington, thirteen miles west of Columbia, a man sitting on the ground did not feel the shock, but saw the top of a lightning-rod in motion on the opposite side of the house and ran around the corner to see who was shaking it.

In a northeasterly direction the shock was reported from points in North Carolina and Virginia over two hundred miles from the origin. At Raleigh, North Carolina, the shock was observed by Professor Collier Cobb, who made a note of it at the time. He states that it lasted thirty seconds or a little more, and was at first thought to be due to the passage of a heavy dray. Several citizens of Danville, Virginia, felt a distinct trembling at the time of the earthquake.

There seems to have been an area in the north central part of North Carolina within which the earthquake was not felt, although it was reported by observers in the surrounding territory. While the shock was very feeble in this region and was consequently felt by few, it is remarkable that reports from five different points within the area mentioned agree in stating that no shock was perceptible. This irregularity in the distribution of the intensities may be due to some local difference in the character of the rocks which rendered them less favorable for the transmission of earthquake vibrations.

The earthquake was undoubtedly due to the differential displacement of rocks under strain. The epicenter was in an area of old crystalline rocks which show no evidence of volcanic activity since Triassic times. In the absence of volcanic disturbances the earthquakes must be attributed to a displacement along an old fault or the formation of a new one. The slight shock felt at West Springs, Glen Springs, and neighboring points in Union county on the afternoon of December 7, 1912, was evidently due to the same cause; and this repetition of seismic activity indicates the probable presence of a line of weakness along which adjustments have taken place in the past, and where similar disturbances may occur in the future.

The circular form of the inner isoseismals may be taken as evidences that the recent displacement was very limited in linear extent; and the relatively small area enclosed by these lines, together with the rapid decrease of the intensity with distance from the epicenter, indicates that the locus of the movement was comparatively near the surface. Additional evidence is furnished by a comparison with other earthquakes of approximately the same degree of intensity. Consi-

ering the relatively high intensity in the epicentral region, the total area in which the shock was felt — about 43,000 square miles — is rather small. The earthquake which occurred in southeastern Maine on March 21, 1904, had a slightly lower maximum intensity, yet it was felt within an area estimated at 300,000 square miles.²

An examination of the isoseismals brings out another important fact: while isoseismals VIII and VII are approximately circular in form, the successive lines of lower intensity become more and more elongated in a northeast-southwest direction; the shock being felt twice as far toward the northeast as toward the southeast or northwest. The greater ease with which the earthquake vibrations were propagated in a northeast and southwest direction is explained by the geologic structure. Most of the rocks in the Piedmont region are highly schistose, the average strike of the schistosity and also of the contacts between different rock formations being in a northeast-southwest direction. Whenever a normal or transverse wave passes from one substance to another differing in density and elasticity, it is in general broken up into four waves: reflected normal and transverse waves, and refracted normal and transverse waves. Waves propagated parallel to the rock structure would undergo much less reflection and refraction than the waves propagated in other directions, and therefore would not be as quickly dissipated.

If the origin had been located at greater depth, where the earth is presumably more homogeneous, the geologic structure would not have been as influential in controlling the propagation of the waves, and the outer isoseismals would probably more nearly approach circular curves.

It is to be regretted that because of insufficient data it is impossible to determine to what extent the velocity wave transmission was influenced by the geologic structure. The shock was recorded on the seismographs at Washington, Cheltenham, New Orleans, Cleveland, and Ithaca, but in most cases it is impossible to accurately distinguish the different phases of the vibration. The earthquake was not recorded at Spring Hill, Alabama, St. Louis, or Albany. Ithaca, the most distant station recording the shock, is over six hundred miles from the origin. The clearest record seems to have been obtained at the Cheltenham Magnetic Observatory of the Coast and Geodetic

² Harry Fielding Reid — The earthquake of southeastern Maine, March 21, 1904. *Bulletin of the Seismological Society of America*, 1911, 1, 47.

Survey. According to a report furnished by O. H. Tittmann, Superintendent, the first preliminary tremors began on the north-south component at 1:28:57 p.m. and the long waves at 1:30:05; the maximum vibrations (0.5 mm.) were recorded at 1:30:35, the end of the principal portion at 1:31, and the end of the earthquake at 1:37. The record on the east-west component was one second behind that of the north-south component. The waves were of short period and small amplitude, being characteristic of an earthquake with the origin located only a few hundred miles away.

UNIVERSITY OF SOUTH CAROLINA,
COLUMBIA, SOUTH CAROLINA

THE HAWAIIAN VOLCANO OBSERVATORY

By HARRY O. WOOD

All who are interested in geophysical studies will learn with interest of work recently inaugurated and now going forward at the crater of Kilauea, the famous basalt vent in the southeast part of the island of Hawaii.

On the brink of this crater an observatory — the Hawaiian Volcano Observatory — has been established recently under the auspices of the Massachusetts Institute of Technology, with Professor T. A. Jaggar, Jr., as Director, to conduct and facilitate study of the volcanoes Kilauea and Mauna Loa. A rather complicated sequence of circumstances has led to the establishment of this observatory. The disposition of a bequest to the M. I. T., the Whitney Fund, designated for the conduct of seismological investigation, led to negotiations which resulted recently in the formation of the Hawaiian Volcano Research Association. This society is made up of individuals and corporations, in Honolulu and elsewhere in the Territory of Hawaii, who have subscribed sums amounting to more than \$5,000 per annum for a term of five years for the support of this observatory. To this amount is joined the income of the Whitney Fund of the M. I. T., the subscriptions of certain citizens of Boston, and small additional appropriations by the M. I. T. The administration of these funds is conducted by the M. I. T., and this institution is thus enabled to go forward with the maintenance of this observatory for five years. It is hoped that an endowment fund will be secured which will place the work and development of the Observatory upon a permanent basis.

The work of the Hawaiian Volcano Observatory, properly speaking, dates from January 1, 1912; a routine of observation has gone on without interruption since January 17, 1912. However, some work done at the earlier dates is so closely connected with that now undertaken at this Observatory as to require brief mention.

In 1909, Professor T. A. Jaggar, Jr., and Professor R. A. Daly, both at that time members of the Department of Geology at the M. I. T., made private expeditions to Hawaii to prosecute geological studies relating to the structure and mechanism of the volcanoes, the tempera

tures of fumaroles and solfataras, and the petrology of the lavas. Their visits led to the negotiations which have resulted in the establishing of the Observatory.

Further, in the summer of 1911 an expedition was sent to Hawaii by the M. I. T. to conduct for a time routine vulcanological observations on the behavior of the active crater and to investigate the temperature of the molten magma. Mr. F. A. Perret, of note for his work on Vesuvius, Etna and Stromboli, and Mr. E. S. Shepherd, of the Geophysical Laboratory, Carnegie Institution of Washington, made up this party; its financial support came chiefly from the M. I. T. and the Geophysical Laboratory, with minor support from the Springfield (Mass.) Volcanic Research Society and small local contributions.

In passing it may be noted that the temperature of the molten magma, at about three feet beneath its surface, was accurately determined by Mr. Shepherd, using a platinum-rhodium thermo-element, at 1010° C.

The routine work conducted by Mr. Perret began on July 2, 1911, and ceased September 17, 1911. As stated above, routine observation was begun at this Observatory on January 17, 1912.

A brief description of the surroundings will facilitate an understanding of the work undertaken here. The crater of Kilauea is a large depression at the summit of the mountain, which is a dome of very gradual slope and unsymmetrical development in the present surface, its flanks on the north and west being buried (if they have had opportunity to form) under the great, high, elongate dome of Mauna Loa, which also is of very gradual slope.

The chief crater, or "sink," of Kilauea is a depression bounded by almost vertical walls which vary in height from a few feet in the southeast portion to over 500 feet on the northwest. It is rudely oval in outline, with a length of over two and one-half miles in the NE-SW direction; and a width, decreasing oval-wise, from one and seven-eighths to one and one-half miles, near the center in the NW-SE direction. At the hotel and near the chief building of the Observatory on the northeast edge, the altitude of the rim of the main crater is 3973 feet above mean sea level.

Within this main crater in its southwest portion is the inner, active pit-crater, Halemaumau, situated at a distance of about one and three-fourth miles, in direct line, southwest of the hotel and Observatory.

Halemaumau is a pit with abrupt walls which vary in apparent height with fluctuations in the altitude of the molten basalt magma, which appears as a seething "lake of fire" filling the bottom of the pit. The upper margin of this active pit forms an oval with diameters of 1200 and 1000 feet approximately, the greatest diameter lying in the WNW-ESE direction. This pit, Halemaumau, is found at the summit of a dome of barely perceptible curvature, which forms the floor of the main crater. This dome is built by overflow from the pit of fresh, glassy basalt, mostly black in color, upon which no vegetation is seen except occasional solitary clumps of ferns or a solitary bush. All this surface is of very recent formation, no part, it is said, being older than 1868. In miniature the surface is very rough from overlapping flows, but viewed as a whole it is a smooth, flat dome — almost a plane.

Near the northern edge of Halemaumau a small, substantial, wood-frame building of two rooms has been built to serve as a shelter for instruments employed for observation and measurement at the edge of the pit, for storage, and as a refuge for observers during intervals in the working time at the "crater,"—for so this inner, active pool is known locally. In this house is a pier, seated upon the fresh basalt, upon which a small recording seismograph will be mounted soon. At the very edge of the northern rim of Halemaumau is a small wooden shelter in which to make observations and measurements of the activity below.

The chief building of the Observatory on the northeast margin of the main crater is a larger, substantial, wood-frame structure containing a photographic darkroom; a workshop and storage-room; a large, well-lighted room for drafting, study, routine work, etc.; a room designed for the storage and exhibit of collections, photographs, seismograms, maps, etc., and the accommodation of visiting workers; and an office room for the Director.

Also there is a basement room, eighteen feet square, with piers and floor of concrete, reposing upon the upper surface of the basalt, and high walls of concrete. This is the Whitney Laboratory of Seismology. A constant emanation of hot steam from cracks in contact with the concrete walls keeps this room at a fairly uniform temperature and thus improves it for the purposes of seismology.

In this laboratory there is now installed one component of a *heavy* Omori horizontal-pendulum tromometer, set up so as to record east-west motion. The "steady mass" of this instrument weighs in excess of 100 lbs. (memorandum of its exact weight is not available), and its

sensitiveness and magnifying power make it competent to register teleseismic disturbances delicately. This instrument has no damping device and possesses an undesirable quantum of frictional resistance. It registers mechanically upon paper, coated with a thin smoke film, wound about a revolving drum.

Pronounced diurnal earth-tilts at this locality have made it necessary to adjust the proper period of this pendulum to about 15 seconds (its present period is 14.5 seconds). Even with such reduced sensitiveness, on occasional seismograms the traces of successive hours are interlaced and intertwined through tilting.

Ordinary microseismic motion is recorded without cessation; and occasionally, with the present static magnification factor of 120, the microseismic waves are very conspicuous.

With two short interruptions, this seismograph has been in operation since early in August, 1912, but thus far only two teleseismic records (at most four, including two records of doubtful meaning) have been written. As yet the writer is uncertain whether this is due to the location of this station on the lip of an open crater above a great magma cistern, to a period of unusual quiet in the Pacific seismic regions, or to defective registration. For, as stated above, there is an undesirable amount of friction in the operation of this instrument.

Up to the time of writing, nearly a hundred weak, feeble, and extremely feeble local shocks have been recorded by this seismograph, systematic report upon which will be made in due course.

A matter of great interest is the registration by this tromometer, almost without cessation but with marked variations in amplitude and energy, of very rapid vibrations of small amplitude, barely visible upon the seismogram except through a magnifying lens. The *period* of these ranges from 0.3 to 0.8 second. The range of their amplitude has not yet been thoroughly worked out. Systematic report upon them and their seismometric dimensions will be given in the routine reports.

Vibrations of this character have been noted by Professor F. Omori in Japan, but only at W. Kohan¹ on the north flank of Utsu-san in connection with the eruptive activity of Utsu-san in July-August, 1910; and during an eruption of Asama-yama at Ashino-taira² on the western slope of this volcano, in this instance only for a few hours in the afternoon of February 4, 1911.

¹ Bulletin I. E. I. C., 5, No. 1, p. 36.

² Bulletin I. E. I. C., 6, No. 1, p. 134.

In the case of the Usu-san eruption Omori found these vibrations to be associated with violently explosive phases of the eruption, and with relatively insignificant smoke jets, in which case he considers the pent up energy to be dissipated in the production of earth-jars.

Here at Kilauea these vibrations clearly increase in energy in a general way when the magma surface is high, is seething violently, and sending up many magma fountains; but so far we have not demonstrated any more intimate relation between their sporadic waxing and waning (they are practically never absent from the seismogram) and variations in the observable energy of eruption. The experience of Omori in Japan together with ours here appears sufficient to establish these as minute elastic disturbances produced by the eruptive action of the volcanoes. Professor Omori has called them micro-tremors. The writer, in view of their manifest origin, and in order to avoid confusing them with microseisms in the technical usage, prefers to call them *volcanic vibrations*.

Besides the heavy Omori tromometer, there is already installed in this laboratory an Omori three-component "ordinary seismograph" for the registration of relatively strong local earthquakes. This is a self-starting, recording seismograph. Thus far no shocks strong enough to write a serviceable record upon its cylinder have started this seismograph.

A two-component Omori horizontal-pendulum tromometer, with light "steady masses," will soon be in operation in the small house beside the inner pit, Halemaumau.

In the main laboratory two components of a 100-kg. Bosch-Omori tromometer, with damping vanes, will be set up in the near future.

We hope to add more precise seismometric instruments later.

Vulcanology, of course, takes precedence over seismology in the program of this Observatory. The strictly vulcanological work thus far undertaken includes:

(a) Direct eye observation of the behavior of the molten magma in the inner pit, noting particularly its motions and the mechanisms of its surface activity.

(b) Photographic records of the phases and stages of its activity.

(c) Plane-table surveys, at frequent intervals, of the altitude and configuration of the surface of the magma column in the bottom of the Halemaumau pit.

(d) Studies of the mechanisms of the miniature flows of the Hal-

emaumau dome as revealed by the structures, surface patterns and textures and miniature physiographic forms of these interwoven flows.

(*e*) Studies of the structure of the Kilauea cone revealed in traverse and in section in the crater region.

(*f*) Also some strictly experimental work with microphones has been attempted, but this has been much interrupted by other work.

It is hoped that before long methods of—

(*g*) Photo-surveying with precise theodolites, and

(*h*) Cinematographic registration of the activity of the molten magma, can be utilized here.

Among other things the following group of special studies has been under consideration, and some of these will be undertaken when circumstances permit:

(*i*) Spectroscopic study of volcanic flames.

(*j*) Optical pyrometry applied to molten magma in the field.

(*k*) Studies of the temperatures of the fumaroles and solfataras in relation to that of the magma.

(*l*) Mineralogy of the Hawaiian solfataric deposits.

(*m*) Angular measurement of rapid changes in the vertical in a volcanic region.

(*n*) Variations in the lower forms of life in relation to volcanic vents.

And also special studies of petrology, physical geography, and structural geology in the Hawaiian Islands.

In addition to this work planned for permanent and transient members of the resident staff, an especial motive of the M. I. T. was to provide a place to which skilled workers in special fields may be invited, to avail themselves of such laboratory facilities and working space as the Observatory affords, though supported by funds under their own control and free to publish as they choose.

THE UNDAGRAPH

By OTTO KLOTZ

At the meeting of the International Seismological Association at Zermatt in 1909 Dr. A. Schuster presented the "Report of the Committee for the Investigation of Microseisms."¹ An important point in this report was that the committee, of which the writer is a member, was voted a thousand marks for the construction of an instrument for the registration of ocean waves, as a close relationship was supposed to exist between them and microseisms. Prince Galitzin reported at Zermatt, too, the result of his observations on microseisms.² At the same meeting Professor Hecker reported on "microseismic movements of short period,"³ as had been requested at the Hague meeting in 1907. The writer had carried on investigations on microseisms for several years, and gave there the conclusions at which he had arrived.⁴ Professor Wiechert had previously announced, based principally from the records of the Göttingen station at Apia, Samoa, that the microseisms in question, those of a period say from four to seven seconds, were due to the pounding of the ocean waves on the seashore. At the time, the writer's definite conclusion, supported by weather charts and seismograms, was that the prerequisite for microseisms at Ottawa was a low barometer with steep gradients along our Atlantic coast, including the Gulf of St. Lawrence.

The strong evidence adduced of some relationship between the ocean and microseisms made it imperative to settle the question definitely, that accurate observations be obtained of the action of the ocean, *i. e.*, of ocean waves. Two questions are here involved: the one the period of the waves, and the other their amplitude. Will the period of the waves be found to be the same as those of the microseisms, or will the latter be modified by geological formations? Will an increase of amplitude of the waves increase their period? Do seismograms at different stations show, for the same time, the same period

¹ Annexe XI, 67, Zermatt Report of 1909.

² Ibid., 68.

³ Ibid., 69.

⁴ Ibid., 73.

of the microseisms? Do microseisms at different stations show a decreasing amplitude due to distance from the ocean, whence the impulses originate? To what extent does the direction of the wind along the seashore affect the intensity of microseisms? To what depths beneath the surface of the earth do microseisms penetrate? May not stations situate to the east of the neighboring ocean predict, from the record of microseisms, the advance of a low, — as the general circulation of the atmosphere in our northern temperate regions is from west to east? — These are some of the questions that were considered and await a definite answer.

As a result of the discussions at the Zermatt meeting, there was built by the Cambridge Scientific Instrument Company under the direction of Dr. Schuster and Horace Darwin, an instrument for counting the ocean waves impinging upon the shore. It will be observed that the instrument only counts the waves, but gives no record of their amplitude or height. This instrument was mounted at the end of a pier at Tynemouth a short time before the meeting of the Association in July, 1911, at Manchester, England, at which meeting some records were exhibited for inspection. They showed a period of about six seconds for the waves there, being for the west side of the North Sea. Although the period was about that of microseisms, still the writer at the time pointed out that Tynemouth was not ideally situated for the mounting of the instrument, but that it should be on some coast exposed to the broad waters of the Atlantic — say on the west coast of Ireland or west coast of Norway. This, however, involved difficulties that at the time were considered insurmountable. In the first place, the instrument requires scientific supervision, and on the sparsely settled west coast there did not appear any available assistance in this respect; and in the second place, the placing of the necessary iron pipe into the water on a coast exposed to the fury of the waves did not promise a successful undertaking. Hence the instrument has remained at Tynemouth.

After returning from the Manchester meeting correspondence was opened with the Cambridge Company for building an "Undagraph," as christened by the writer, — possibly some professor has anticipated him. It was the intention of the writer that the instrument record not only the period but also the amplitude of the waves, for only then is it possible to make the proper comparison between an "undagram" and a seismogram. The Cambridge people, however, foresaw so many

difficulties in building it and in the supervision at the seacoast by probably unscientific hands, that finally the order was given for an instrument which only records the period.

During the past summer the writer visited the Atlantic coast of Nova Scotia and Newfoundland, and finally selected Chebucto Head, outside of the harbor of Halifax, for mounting the undagraph. The place is thoroughly exposed to the Atlantic and presents a bold, rocky, granitic face. Of the immense force of the waves one saw an exhibit there in the form of rails extending from the cliff and serving for unloading coal, which were twisted and bent like wire. There is a lighthouse at Chebucto some eighty feet immediately above the water, and in which it is intended to place the recording part of the apparatus. It was fortunate to find in the rock a split or cleft leading from the water towards the summit of the cliff, and into which it is intended to imbed in cement the iron pipe, the function of which will be given presently. The undagraph has recently been received here, and has some improvements that were suggested from the experimental one set up at Tynemouth.

The principle of the instrument is simple, although quite a bit of mechanism is involved. An open iron pipe extends into the sea with its mouth below the lowest stage of the tide or wave trough; the other end of the pipe on land is attached to a cell with diaphragm of leather, which replaces the mercury manometer of the experimental instrument. As waves pass over the submerged mouth of the pipe, the water rises in the pipe to the height of the wave, thereby compressing the air in the pipe and consequently bulging the diaphragm, whereby an electric contact is made. Hence every wave sends a current through an electro-magnet, which works a ratchet-wheel. Here we have, then, our initial recording or counting of the waves that impinge upon the shore. The ratchet-wheel has 120 teeth, and on its axis there is fixed a cam which operates a pen, and this pen moves across the paper in a diagonal line and returns to zero at every 120th wave. The paper is driven by a pendulum clock. Beside the record of this pen, there is another pen which records the time, *i. e.*, draws a line at the edge of the paper, having a break every hour, the length of the hour being 6 cm., so that each minute is represented linearly by 1 mm.

On the strip of paper we then have the time-scale represented by the hour-break line, and adjoining it a series of minutely serrated inclined lines, the inclination depending upon the period of the waves.

If, for instance, there were a period of half a minute, then this inclined line would extend over the whole distance covered by the hour, 6 cm; for the pen returns only after 120 contacts, and in our supposed case this would be after 120 half-minutes, or one hour. When the period is five seconds, then we would find six inclined lines during one hour, for each line would represent in time 120×5 or 600 seconds, i. e., 10 minutes, hence six to the hour.

With our Bosch photographic 200-gram seismograph (damped of course) we get very fine records of microseisms. The nearest part of the Atlantic is approximately 500 kilometers distant; while to Chebucto, where the undagraph is to be mounted, is 1000 km., in round numbers. In how far the periods recorded by the ocean waves will synchronize with those of the seismogram, we will have to await. As we get microseisms due to lows passing along about 2000 km. of coast line, say from Cape Hatteras to Newfoundland, theoretically there should be undagraphs distributed along the whole of this stretch in order to correlate more intimately ocean-waves and microseisms. I use the words low and ocean-waves somewhat synonymously, as, ordinarily speaking, there can be no ocean-waves without the presence of a low.

It is regretted that the instrument does not give the amplitude for a complete comparison between the undagram and seismogram, and also for establishing the relation, if any, between the amplitude of the ocean-wave and its period. The particular value of the record from Chebucto is, that it will be from the open ocean, the action of which it is, we believe, to be the *causa belli*, and not of the waves found in bays or protected parts. But this very exposure, as already intimated, causes much anxiety as to the permanence or stability of the iron pipe leading out into the sea, to withstand the force and fury of the waves. Nous verrons.

The accompanying photographs, Plate I, are fairly self-explanatory. The one shows the recording device, and adjoining it the diaphragm with electric contact and connection for pipe from the sea; the other shows more in detail the important part of the recording device. On the latter figure no paper is shown on the cylinder.

DOMINION OBSERVATORY
OTTAWA, CANADA.

DETERMINATION OF THE CONSTANTS OF A SEISMOGRAPH

By HARRY FIELDING REID

I. DETERMINATION OF THE STATIC MAGNIFYING POWER

In order to calculate the amplitude of the earth vibrations from the record of a seismograph, several constants of the instruments are needed, namely: the magnifying power for infinitely rapid vibrations, or the *static* magnifying power; the period; the damping; and the frictional constants. To these may be added the quantity i , which has various meanings for various forms of instruments, as will appear further on. In the determination of these constants other constants must be used, such as the distances of the centre of gravity and the centre of oscillation from the axis of rotation. The various methods of determining these constants are collected together here. The formulae used are not deduced, as this would lead us too far into the elements of rigid dynamics; but the simpler formulae can always be found in text-books of that subject; and the derivation of those applying specifically to seismographs may be found in papers dealing with the theory of seismographs.¹ We shall confine our attention to seismographs recording by the ordinary mechanical or optical methods, and shall not consider seismographs of the Galitzin type, recording through a galvanometer.

The static magnifying power of a seismograph is defined as the ratio of the displacement of the recording point, measured on the record, to the corresponding relative displacement of the centre of oscillation of the pendulum. If, therefore, we can displace the centre of oscillation through a measureable or calculable distance and at the same time measure the corresponding displacement of the pointer, we can immediately calculate the static magnifying power.

¹ E. Wiechert, "Theorie der automatischen Seismographen." Abh. Kön. Gesel. Wiss. Göttingen. Math-phys. Kl. 1902-1903, 2, 1-128.

Prince B. Galitzin, "Ueber Seismometrische Beobachtungen." Acad. Imp. Sciences, St. Petersburg, 1902. Comptes Rendus Com. Sismique Permanente. 1, 101-183.

H. F. Reid, "Theory of the Seismograph." The California Earthquake of April 18, 1906, 2, Appendix.

All seismographs in use move by rotating around an axis.

Let

L = distance from the axis of rotation to the centre of oscillation,

θ = angular displacement of the seismograph pendulum,

a = the corresponding displacement of the pointer,

V = the static magnifying power.

Then $L\theta$ is the displacement of the centre of oscillation and

$$V = \frac{a}{L\theta}. \quad (1)$$

There are several methods of determining L and θ separately; and their product may also be directly determined.

A. DETERMINATION OF L .

1. L depends only on the distribution of the mass of the pendulum, and is given by the equation

$$L = \frac{I}{Ml} \quad (2)$$

where

I = moment of inertia of the pendulum about the axis of rotation,

l = distance of the centre of gravity from the same axis,

M = mass of the pendulum.

M is determined directly by weighing. If the pendulum is of a sufficiently simple form, I and l can be calculated, after weighing the different parts and measuring their distances from the axis. l can also be found by balancing the pendulum on a sharp edge, as usually explained in elementary text-books of physics.

2. Another way of determining L is to hang the pendulum by its axis and let it swing as an ordinary pendulum. If T' is the period observed in this position, then

$$L = g \left(\frac{T'}{2\pi} \right)^2. \quad (3)$$

This method can be modified as follow: hang the pendulum by any point, and let it swing as an ordinary pendulum in the same plane with

respect to itself that it swings in when recording; determine its period, which will satisfy the following relation:

$$\frac{T'^2}{4\pi^2} = \frac{I_0 + Ml'^2}{Ml'g}, \quad (4)$$

where I_0 is its moment of inertia about the centre of gravity, and l' is the distance from the centre of gravity to the point of suspension. Then

$$I_0 = Ml'g \frac{T'^2}{4\pi^2} - Ml'^2; \quad (5)$$

and if the centre of gravity is distant l from the actual axis of rotation when recording, then

$$I = I_0 + Ml^2 \quad (6)$$

or

$$I = M \left(gl' \frac{T'^2}{4\pi^2} - (l' - l)(l' + l) \right). \quad (7)$$

L can then be calculated through equation (2).

This method is well adapted to determine L for light pendulums or for determining the moment of inertia of the beam of a pendulum after removing the heavy mass; no errors will arise on account of irregularities of form. The total moment of inertia will then be given by adding the moment of inertia of the heavy mass, which is usually of a simple form and can easily be calculated. The proper formula for it will be found in elementary treatises on rigid dynamics. The moment of inertia of a magnifying lever can well be found by this method; as the lever is usually supported at its centre of gravity, the moment of inertia desired will be given directly by equation (5); this moment of inertia is the quantity I' of equations (8) and (9).

When the movement of the pendulum is magnified mechanically by means of levers, the value of L is somewhat increased, because the force acting must move the levers as well as the pendulum; and, moreover, the angular velocity of the levers is always greater than that of the pendulum. We have for the pendulum without the levers,

$$L = \frac{I}{Ml} = \frac{MLl}{Ml}; \quad (2)$$

with the levers,

$$L = \frac{I + n_1^2 I' + n_1^2 n_2^2 I'' + \text{etc.}}{Ml}; \quad (8)$$

and the increase in L is

$$\frac{n_1^2 I' + n_1^2 n_2^2 I'' + \text{etc.}}{Ml}, \quad (9)$$

where $n_1 = l_1/l_2$ and $n_2 = l'_2/l_3$ (see figure 1); I' is the moment of inertia of the first lever about its pivot, and I'' that of the second lever about its pivot; n_1 and n_2 can readily be measured. I' and I''



Figure 1.

can be determined by weighing and measuring the levers or by swinging them; M and l , which retain their original values and are not altered by the levers, must be known to a reasonable degree of accuracy. This corrected value of L must be used in determining V . When a single light lever is used with a fairly heavy pendulum, the correction of L is small.

The usual method of determining the moment of inertia of a magnet from its period before and after adding an additional mass of known moment of inertia, is not well adapted to pendulums and seismographs, and need not be given here. For other methods of determining L see under C1 and D2.

B. DETERMINATION OF a/θ .

1. Displace the pendulum and measure directly the angle θ . This can be done by attaching a mirror to the pendulum and determining the angle by means of a telescope and scale, such as are used with reflecting galvanometers. The pendulum may be displaced by leaning a small weight against it, by tilting the instrument (see below), or in any other convenient way. It is not necessary to know the force exerted by the weight.

We may also displace the pendulum by letting it rest against the end of a screw supported by a solid stand, and turning the screw. If the screw advances a distance c , and if it touches the pendulum at a distance l' from the axis of rotation, then $\theta = c/l'$. a is measured and the ratio a/θ calculated.

In measuring a with mechanically recording seismographs, care must be taken that its value is not affected by the friction of the marking point. The friction may be nullified by gently lifting and dropping the recording point.

2. The ratio of a to θ can be calculated from the relation

$$\frac{a}{\theta} = \frac{l_1 l'_2 l'_3}{l_2 l_3} = n_1 n_2 l'_3 = m_2 m_3 l_1 \quad (10)$$

where $m_2 = l'_2/l_2$, $m_3 = l'_3/l_3$; as will appear from figure 1. The n 's or m 's can easily be measured. This ratio can then be introduced immediately into equation (1) without measuring either a or θ .²

3. With instruments registering optically by the reflection of a beam of light from a single mirror on the pendulum,

$$\frac{a}{\theta} = 2d, \quad (11)$$

where d is the distance of the mirror from the recording drum. If several reflections were used, equation (11) would have to be somewhat modified.

The Milne horizontal pendulum registers by projecting optically a point near the end of the beam against the recording paper. If this point is at a distance, l_1 , from the axis of rotation

$$\frac{a}{\theta} = l_1. \quad (12)$$

The same expression holds for instruments recording mechanically, if they have no magnifying levers; l_1 is the distance to the recording point from the axis.

C. DETERMINATION OF THE PRODUCTS $L\theta$.

1. If we allow the pendulum to swing in its usual position, the following relation will hold:

$$\left(\frac{2\pi}{T}\right)^2 = \frac{gi}{L}, \quad (13)$$

where

T = period of pendulum,

g = acceleration of gravity,

i = a quantity different with different types of instruments, but constant for the same instrument swinging in a definite period. For ordinary pendulums $i = 1$; for horizontal pendulums i is the angle between the axis of rotation and the vertical; for inverted pendulums and vertical motion seismographs i is a function of gravity and the strength of the springs which hold the pendulum in position.

If we tilt the instrument through an angle, ω , the pendulum will be displaced through an angle θ given by the relation

$$\theta = \frac{\omega}{i}. \quad (14)$$

Eliminating i between (13) and (14) we find

$$L\theta = \frac{g\omega}{n^2}, \quad (15)$$

where n^2 is written for $(2\pi/T)^2$. The L used in this method includes the correction for the levers, if they are connected up when the period is determined.

For instruments mounted on an iron stand provided with leveling screws, a tilt can easily be produced with these screws; and the amount calculated by the angle through which the screw is turned, the pitch of the thread and the distance of the screw from the line about which the stand is turned. Horizontal pendulums provided with adjusting screws at the upper support can be tilted by moving this point. If δ is the distance the upper support is moved, and λ the distance between the two points of support, then $\omega = \delta/\lambda$.

In the case of ordinary vertical pendulums i becomes unity, equation (13) becomes identical with equation (3), and the method reduces to the simple method of A2.

In the case of vertical motion seismographs, equation (14) does not hold; so that the method just given cannot be applied to such instruments.

If θ is measured, say by a mirror and telescope, we can calculate L from equation (15); but this is not a very good method.

2. When the pendulum of a seismograph is displaced through a small angle, θ , the moment of the force of restitution, f , is proportional to θ ; that is,

$$f = \mu\theta; \text{ or } \theta = \frac{f}{\mu}, \quad (16)$$

where μ is an undetermined constant.

If f is a measured moment, θ is known when we know μ . This latter can be found through the period; for the relation holds

$$\left(\frac{2\pi}{T}\right)^2 \text{ or } n^2 = \frac{\mu}{I}; \therefore \mu = n^2 I. \quad (17)$$

Substituting this value of μ in (16), and replacing I by its equivalent, MIL , we find

$$\theta = \frac{f}{n^2 I} = \frac{f}{n^2 MIL}, \quad (18)$$

and

$$V = \frac{a}{L\theta} = \frac{n^2 Mla}{f}. \quad (19)$$

This method is due to Professor Wiechert, and is convenient for determining the magnifying power of inverted pendulums, and vertical motion seismographs. n^2 is found through the period; M is determined by weighing; l is found by calculation from the form of the pendulum, or by balancing the pendulum on an edge. Professor Wiechert determined f in the following way: a small apparatus, like the beam of a chemical balance with a long pointer, is balanced on a frame above the pendulum with the end of the pointer touching the pendulum at a point distant l' from the axis of rotation of the seismograph. If a small mass, m , is placed at the end of the balance-arm, and this arm equals the length of the pointer, then the force with which the pointer presses against the pendulum is mg , and the moment is $mg l'$. If this value for f is substituted in (19), it becomes

$$V = \frac{n^2 Mla}{m l' g}, \quad (20)$$

In applying this method to vertical motion seismographs we have merely to lay a small mass, m , on the beam at a distance l' from the axis of rotation, and equation (20) can be used immediately for calculating V .

If the angle θ is determined, we can calculate the value of L by equation (18). If the magnifying levers are connected to the pendulum when the period is determined, no correction of L on account of the levers is required. This method would not in general be used to determine L , except for an inverted pendulum or a vertical motion seismograph.

Any of the methods given may be applied as well to vertical motion as to any form of horizontal motion seismographs, with the exception of the first method of determining the product $L\theta$.

D. MAGNIFYING POWER FOR TILTS.

1. The fundamental relation between a steady tilt and the corresponding angular displacement of the pendulum is given by equation (14), which is

$$\omega = i \vartheta. \quad (14)$$

If instead of measuring ϑ directly we measure a , the displacement of the recording point, then

$$\omega = \frac{ia}{n_1 n_2 l'_3} = \frac{ia}{m_2 m_3 l_1} = \frac{ia}{VL}. \quad (21)$$

The quantity i is intimately related to the magnifying power for tilts. If we define this magnifying power as the ratio of the angular displacement of the marking lever to the tilt of the ground, then its value will be given by $n_1 n_2 / i$, as a / l'_3 is the angular displacement of the marking lever.

We determine i as follows: produce a known tilt by one of the methods given under C 1; and measure ϑ , or a and the other quantities which occur in equation (21), and then calculate i by equation (14) or (21).

We may express equation (21) in the form

$$\omega = c_1 a, \quad (22)$$

where for a given instrument c_1 is constant as long as i is unchanged; the value of c_1 will depend on the units used in expressing ω and a . If the former is expressed in seconds of arc, and the latter in millimeters, and the value of c_1 determined accordingly through equation (22), then ω and a must always be expressed respectively in the same units, if we wish to use the same value of c_1 . (See under 3 below).

2. If we allow our seismograph to swing in its ordinary position when recording, its period is given by equation (13); if now we allow it to swing as an ordinary pendulum, its period is given by equation (3). From these two equations we find

$$i = \frac{T^2}{T^1}. \quad (23)$$

This method is very good for determining i for some light pendulums.

Since T' is always determined without the magnifying levers, the levers should be disconnected when T is determined.

We find from equation (13)

$$iT^2 = \frac{4\pi^2 L}{g}, \quad (24)$$

If L has been determined by any of the methods given under A, then i can be calculated from equation (24) after determining T . The values of L and T must both be determined with the magnifying levers, or both without the magnifying levers.

We can reverse this method, and calculate L from equation (24) after i and T have been found.

3. The period of the pendulum is usually altered by changing the value of i . Equation (24) shows that the product iT^2 is constant for a given pendulum; therefore if we change i and T the following relation will hold (using subscripts to denote the two cases):

$$i_1 T_1^2 = i_2 T_2^2. \quad (25)$$

If i_1 and T_1 have once been determined for a given seismograph, we can determine the value of i_2 merely by determining T_2 . This affords a simple method of calculating the changed magnifying power for tilts when the period of the seismograph has been altered. (See equations (21) and (22).)

4. The following method of determining both L and i is given by Prince Galitzin: Equation (13) can be written

$$\frac{4\pi^2 L}{g} - T_0^2 i_0 = 0. \quad (26)$$

Write $4\pi^2 L/g = y$; $i_0 = x$; and the equation becomes

$$y - T_0^2 x = 0. \quad (27)$$

Suppose we alter i_0 successively by Δi_1 , Δi_2 , etc. (we can do this in the same general way given for producing tilts, C1), and find the corresponding periods, T_1 , T_2 , etc; equation (27) takes the form

$$\begin{aligned} y - T_0^2 x &= 0, \\ y - T_1^2 x &= T_1^2 \Delta i_1, \\ y - T_2^2 x &= T_2^2 \Delta i_2, \\ &\text{etc.} \end{aligned} \quad (28)$$

Add all these equations and divide by the number of equations and we get

$$y - Ax = B \quad (29)$$

where A is the average value of T^2 , and B is the average value of $T^2\Delta i$. Subtract (29) from each of (28) and we get a series of equations of the form

$$x(A - T_1^2) = T_1^2\Delta i_1 - B,$$

or

$$x = \frac{T_1^2\Delta i_1 - B}{A - T_1^2}. \quad (30)$$

We find as many values of x as there are equations (28) and the average may be taken as the best value of x or of i_0 . Substitute the average value of x thus found in each equation (28) and we get a series of values of y . The average of these will be the best value of y ; and then $L = gy/4\pi^2$.

SEISMOLOGICAL NOTES

Earthquakes on Terceira, Azores Islands.—On the 29th of October, 1912, the island of Terceira, one of the Azores group, was shaken by a severe earthquake. The following details have been gathered from the reports of the newspapers, and especially from the *Diario de Angra do Heroismo* of November 8 and 9, 1912.

At Villa da Praia the first shocks were felt about three o'clock on the morning of October 29th, and continued to be felt up to and including November 12th. These shocks were not destructive, but they kept the people in a state of nervous alarm. At 9 p.m. on the 6th there was a loud subterranean rumbling accompanied by a vertical jar that sent the entire panic stricken population of the town into the streets and on to the seashores, where most of them passed the night. At 11 o'clock that night there was another shock. At 3 o'clock and again at nightfall of the 7th there were more shocks, none of them severe, but long continued oscillations. The damage done was slight, only a few buildings being cracked. Many people, however, fled from Villa da Praia to the adjacent towns.

Venezuela earthquake of January 13, 1913.—An earthquake shock was felt over a triangular area between Aragua de Barcelona, Barcelona, and Cumaná, Venezuela, on January 13, 1913, at 1:30 p.m. The shock did no damage. A rumbling sound and a rush of air are reported as immediately preceding the shock. Some say that the sound resembled the starting of the gas engine at the Cumana cotton factory. The shock was not felt across the gulf on the Peninsula de Araya.—Letter from F. S. Prout.

Colima in eruption.—The volcano of Colima, state of Jalisco, Mexico, is said to have broken into violent eruption on January 20th. It is reported that the eruption was chiefly in the forms of gases and volcanic ashes that fell over a wide area, and, in places near the volcano, to a depth of several feet. Ashes fell as far north as Guadalajara, a distance of a hundred miles.

Shock at Constantinople.—A severe earthquake was reported at Constantinople at 4 o'clock on the morning of January 25, 1913, but there was no loss of life.

Earthquake of February 22, 1913, in Ecuador.—There was a violent earthquake at Guayaquil, Ecuador, at 9:40 p.m. on February 22nd. The people were panic stricken, and rushed into the streets. The first shock is said to have lasted more than a minute, and this was followed by several lighter after-shocks during the night of the 22nd and on the 23rd, but no damage is reported in that place. The city of Guayaquil is built upon low, flat ground, on the west bank of Rio Guayas, near and lapping up against the base of the Cerro de Santa Ana, a low Cretaceous hill. This earthquake was generally felt throughout Ecuador; it was most severe in the provinces of Loja, Azuay, and Canar, where houses were thrown down; it was also felt in the northern part of Peru.

Others shocks in Ecuador.—Cable reports from Guayaquil, Ecuador, say that earthquakes occurred in that country the night of February 26, 1913. They are said to have been especially severe at Cuenca, and in the vicinity of Chimborazo at Ambato and Riobamba—all of them in the Andes. Again on March 1st and 2nd light shocks were felt at Guayaquil.

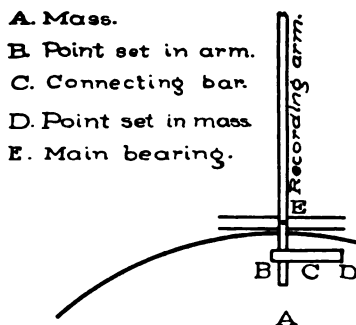
An earthquake in Guatemala.—A severe earthquake occurred on the morning of March 8, 1913, in the Province of Santa Rosa, Republic of Guatemala. It is reported that the city of Cuajiniquilapa, capital of the province, was destroyed, and that all villages within a radius of eighteen miles were much damaged. Many lives are said to have been lost, but no trustworthy account of the catastrophe has reached us.

A shock at Medford, Oregon.—A slight earthquake is reported from Medford, Oregon. It occurred at 12:40 p.m. March 15, 1913: no damage was done.

A new station at Victoria.—A new station for meteorological and seismological work is to be erected at Victoria, British Columbia, according to a news item from that city. An acre and a fifth of land on

Gonzales Heights, two hundred and ten feet above sea level and commanding an unobstructed view, has been purchased by the Dominion government, and plans for the buildings are being completed by Mr. F. Napier Denison of the local meteorological office. A sum of nearly \$20,000 has been appropriated for the observatory. Beside the installation of seismographs, the scope of the weather observations is to be extended by cooperation with the wireless station.

A suggested improvement of the seismograph.—Our colleague, Mr. L. S. Metcalf, of Bath, Maine, has made a change in his Omori seismograph that will interest those who have the same type of recording arm. Mr. Metcalf writes: "As the Omori seismograph is usually made, the beam carrying the mass, the recording arm, and the tracing finger are supported by cone and point bearings, and therefore friction in those parts is reduced to a minimum. But connection between the recording arm and the mass is made by pressure, by means of a spring or a weight, of the arm against a plate erected in the mass ;



hence at that point considerable friction remains. Cone and point bearings can be used here also, and the last cause of friction nearly removed, while preserving rigidity and freedom of motion, by fixing a point into the upper side of the arm *B*, and another in the mass *D*, and connecting the two by a bar of proper weight having conical cavities in its under side *C*."

Earthquake in New Zealand.—An earthquake is announced from Wellington, New Zealand, on February 26, 1913. Its precise location is not stated, but it seems to have been in the vicinity of the city of

Wellington, where chimneys were shaken down and buildings damaged. The disturbance is said to have begun with a series of minor shocks, which were followed by a loud explosion. No loss of life is reported.

Determination of the epicenter.—The following communication by B. Galitzin and George W. Walker is taken from *Nature* of September 5, 1912.

It has been proved by observation with the Galitzin seismographs, both at Pulkowa and Eskdalemuir, that when the first phase *P* of an earthquake is sharp, the azimuth of the epicenter from the station is uniquely determined by the observations at that station. It follows that if the azimuth of the epicenter is determined at two independent stations suitably situated, the epicenter can be determined from these two azimuths alone.

We have to-day, as an example, verified by construction and by computation that this principle gives accurately the epicenter of the earthquake that occurred in Monastir on February 18, 1911.

The azimuth observed at Pulkowa was $22^{\circ} 53'$ west of south, while the azimuth observed at Eskdalemuir was $55^{\circ} 56'$ east of south. The resulting epicenter we find to be 40.5° N., 20.3° E.

The epicenter deduced by the Pulkowa observations of azimuth and epicentral distance was 40.5° N., 20.1° E.; while the similar deduction from the Eskdalemuir results was 40.3° N., 20.4° E.

It is clear that in this case the accuracy of determination from the azimuths alone equals that of the determinations from the separate stations, and it is known that the earthquake did occur in the region indicated.

The advantages of this new method based on azimuths alone are:

1. That it is independent of any time reckoning whatever at the two stations.
2. That it is independent of the determination of the second phase *S* on a seismogram (which is frequently difficult to fix with certainty).
3. That it is independent of any empirical tables for epicentral distance, which are admittedly only approximate.
4. Although only two stations are used, the determination is unique.

We may observe that for a given case the accuracy of determination depends on a suitable choice of the two stations.

Shinobu Hirota returns to Japan.—The following letter by Professor Milne appears in *Nature* of December 19, 1912.

Shinobu Hirota, who returns to Japan at the end of this month, by his doctor's advice, came with me to this country in 1895, and within a week of his arrival the seismograph which he brought with him from Japan was at work at Shide. To convince those who had doubts as to the possibility of recording in Britain earthquakes which had originated even so far away as their anti-



podes, a second instrument was installed at Carisbrooke Castle. To look after this Hirota had, wet or fine, a daily walk of four miles. The fact that these two instruments gave similar records and also that from a single record we could tell the distance at which a megaseism had originated naturally attracted some attention. Directly it was shown that certain earth disturbances had interrupted cables, Colonies desirous of knowing the cause of these sudden isolations from the rest of the world set up seismographs.

This was the commencement of the British Association cooperation of seismological stations, now sixty in number. To bring this into being Hirota played an active part. He knows personally many of the directors, and has given instruction to their officers. In practical seismometry he has made many innovations, some of which will perhaps be looked upon as "mere dodges," but they have rendered instruments more sensitive. His multiplying levers made of grass stems gathered from "bents" give pointers exactly one-third the weight of their equivalent in aluminum, and yet twice, if not three times, as stiff. It was by using these that we got at Bidston, where Hirota went to set up an instrument, the first records of rock deformation due to tidal load.

In the workshop he is a good all-round workman, in the observatory and office he has kept most careful records, could calculate a chordal distance, make a zenithal projection or an observation for time, while for photographic work he holds a gold medal from the Photographic Society of the Isle of Wight. Above this, his sharp eyes would find on a seismogram two records where at other stations only one had been discovered. In view of the great attention and large sums which have now been spent, particularly in foreign countries, on the new seismological departure, I feel myself justified in giving recognition to an assistant pioneer in these new studies. Illness carries him back to his native country, where I trust he will have a speedy recovery. His work is embodied in annual seismological reports of the last seventeen years and twenty-six circulars giving the records received from observatories cooperating with the British Association.

J. MILNE.

SHIDE, NEWPORT, ISLE OF WIGHT.



REVIEWS

THE REGISTRATION OF EARTHQUAKES AT THE DETROIT OBSERVATORY FROM AUGUST 16, 1909, TO JANUARY 1, 1912. By Walter M. Mitchell. *Publications of the Astronomical Observatory of the University of Michigan*, 1, 54-79. Ann Arbor, 1912.

The observatory is equipped with two Strassburg 100 kg. tromometers by Bosch; one Wiechert horizontal seismograph, with steady mass of 100 kg.; and one Wiechert vertical seismograph, with steady mass of 80 kg.

Among other valuable matter this report gives the following results of the observatory's experience with the two types of seismographs.

Comparing the Wiechert horizontal seismograph with the Strassburg tromometers, the latter type of instrument has proved more satisfactory for the following reasons: It is decidedly more sensitive, and in practically all cases of near and distant shocks the records are more legible, and are probably more accurate. There has been very little recorded on the Wiechert instruments that has not been recorded also on the Bosch tromometers. The reverse of this is, however, not true. Microseisms have been recorded many times on the Bosch instruments of which there was not the slightest trace on the Wiechert instruments. The most serious fault of the Wiechert instruments, in addition to that already mentioned, is one of design: namely, that the earthquake record and the time signals are both made by the same recording point. If the shock is a severe one, the time signals become completely obliterated, and the times of the phases cannot always be determined. In addition, the rate of the driving clock is so very irregular that the times cannot be estimated to within a quarter of a minute after an interval of five minutes. (p. 62.)

On the other hand, in referring to the grouping of the vibrations of microseisms, the author says:

The grouping is conspicuous on the Wiechert records. The groups are more sharply defined than on the Bosch records: that is, the recording point comes to a period of absolute rest between the groups of microseisms, while the beginning and ending of each group is quite abrupt. This is doubtless a damping effect. It is rather curious that the vibrations in these groups on the Wiechert record are sometimes decidedly irregular, and at other times are quite regular. The Bosch record is, however, the same at both times, and nothing can be learned from it regarding the kind of "regular" microseisms that will be found on the Wiechert record. The irregular microseisms occur less fre-

quently than the regular. They show nothing of the group arrangement, but consist simply of continuous vibrations of irregular period and unequal amplitude. Similar to the regular microseisms just described, they commence and end gradually. Rather strangely, microseisms of this class are rarely recorded by the Wiechert instruments; even when very strong movement has been recorded on the Bosch records, there is not the least trace of this on the Wiechert record. For recording microseisms the Bosch instruments at this observatory are decidedly superior to the Wiechert.

The observatory records show that—

Here as at other stations local winds, temperature changes, and pressure gradients appear to be without direct effect in producing these disturbances. It has been observed here, as elsewhere, that the microseisms are more frequently seen in the winter season than in the summer.

Wiechert and Linke's hypothesis that this kind of microseisms is due to the pounding of the surf is rejected for the Ann Arbor station. Klotz has observed that the microseisms at Ottawa occur when a low pressure area exists over the Gulf of St. Lawrence, and increases in intensity when there is also a high pressure area on the Atlantic coast north of Florida; and at Ann Arbor there is some evidence suggesting a correlation between the prevalence of lows over the Gulf of St. Lawrence and microseismic activity, although the relation does not always obtain.

C. F. TOLMAN.

ON THE EARTHQUAKE OF JANUARY 2, 1912, IN THE UPPER MISSISSIPPI VALLEY. By Anton D. Udden. *Transactions of the Illinois Academy of Science*, 5, 1912 (4 pages not numbered).

The earthquake described in this paper occurred in Illinois at 10:15 to 10:35 a.m. on January 2, 1912, and was felt over an area of 40,000 square miles. Mr. Udden's paper is based upon reports gathered from about one hundred and fifty localities. The epicenter was in Illinois between the towns of Morris and Aurora, where the shock had an intensity somewhat above VI of the Rossi-Forel scale. The reports show that it was observed throughout Illinois north of Springfield, through southern Wisconsin, northwestern Indiana, and eastern Iowa. The paper is accompanied by an interesting small map on which are drawn the isoseismals of the shock described and also those of the earthquake of May 26, 1909, which affected about the same area. (See this BULLETIN, 1, 25.) As the author well observes: "the coincidence of these two earthquake areas can hardly be regarded as a matter of chance."

J. C. BRANNER.

CATALOGO DE LOS TEMBLORES (MACROSEISMOS) SENTIDOS EN LA REPUBLICA MEXICANA Y MICROSEISMOS REGISTRADOS EN LA ESTACION SEISMOLOGICA CENTRAL, TACUBAYA, D. F., DURANTE EL AÑO 1910, etc. *Paregones del Instituto Geologico de Mexico*, tomo III, numero 10, 1911. Mexico, 1911.

This catalogue of the earthquakes that occurred in Mexico in 1910 shows that the majority of shocks were local, affecting a relatively small area, only a few being registered at a number of localities; and, in order to determine the total number of earthquakes during the year, corrections have been made as far as possible for shocks that were felt at more than one place.

The following is a list of microseisms by months:

January	16 shocks	July	5 shocks
February	17 "	August	10 "
March	13 "	September	10 "
April	15 "	October	2 "
May	12 "	November	3 "
June	3 "	December	8 "
		Total	114 "

No shock of high intensity was recorded for the year, the range being from II to V in the Cancani scale. No injury to property is noted except in one case in which there was a slight disturbance of the roof of a house. Out of a total of 114 shocks, 12 were preceded and 20 were accompanied by subterranean noises. In one case a loud noise both preceded the earthquake and occurred again ten minutes after the shock. Forty shocks were registered in the state of Guerrero, 38 in Oaxaca, and twenty-one in Colima.

The earthquake of May 31, 1910, was the most widely felt shock of the year, thirty-one observers scattered over the states of Guanajuato, Guerrero, Vera Cruz, Morelos, Oaxaca, Mexico, Michoacan, Puebla, and Tlaxcalla recording the Greenwich time as 4 hours 57 minutes. At Ayutla, Guerrero, the time was 4:55. One observation in Vera Cruz and two in Puebla recorded 4:58, and at Toluca, Mexico, the time was 4:59. The nearly simultaneous occurrence of this earthquake over such a large area suggests a very deep center of disturbance. During the last six months of the year 1910, 94 microseisms were recorded at the Central Seismological Station, 15 at the station at Mazatlan, and 30 at the station of Oaxaca.

C. F. TOLMAN.

EL TEMBLOR DEL 7 DE JUNIO DE 1911 (The Mexican earthquake of June 7, 1911). Por Manuel Miranda y Marron. Société Scientifique "Antonio Alzate." *Mémoires*, 32, 27-66, 1911-12.

The earthquake described in this paper was one of the most severe experienced in Mexico during recent years. The center of the disturbance was in the state of Jalisco, fifty miles northeast of the volcano of Colima, and seventy-five miles south of the city of Guadalajara. Over an area of some two thousand square miles, with Guzman and Tuxpan near the center of it, the intensity was between IX and X, R.-F. scale. The principal shock occurred about 4:25 a.m., and lasted for more than a minute. In the city of Guzman the damage was enormous. The Jefe Politico, Don Federico Arias, reported from that city 35 persons killed and 53 wounded out of a population of about 16,000, while 119 houses were destroyed and 500 were rendered unfit for use.

J. C. BRANNER.

*DIE SEISMISCHEN REGISTRIERUNGEN IN HAMBURG, vom 1 Januar 1910 bis zum 31 Dezember 1911. By Dr. E. Tams. Hamburg, 1912.

This bulletin contains records of all the distant earthquakes registered by the seismographs of the Physikalischen Staatslaboratorium at Hamburg during 1910 and 1911. The seismographs which furnished the records are: (1) Wiechert's inverted pendulums for N-S and E-W components, mass of each pendulum 1000 kg., free period 10 sec., damping ratio 5 to $5\frac{1}{2}$, magnification 190. (2) Hecker's horizontal pendulums for N-S and E-W components, free periods 17 and 18 sec., damping ratio 5 to $5\frac{1}{2}$, magnification 32.

During 1910, 391 earthquakes were registered and 381 in 1911. The published records give date, time, phases, periods, and amplitudes for most of these. In many cases the amplitudes are little or no greater than those of the microseismic disturbances which are continually registered almost without interruption by the Wiechert pendulums. The earthquakes are generally distinguished from the microseismic disturbances by their longer periods.

For about five or ten per cent of the records, the times of arrival of the first and second preliminary tremors are sufficiently well marked to allow of a determination of the distance of the epicenter. Where possible, these earthquakes are identified with ones which have been reported from various parts of the world. For ten earthquakes dur-

ing the two years the registration of the first few (one to three) impulses was sufficiently distinct to allow of the determination of the azimuth in which the earthquake waves arrived at Hamburg. The method used was that introduced by Prince Galitzin. The first waves which arrive from a distant earthquake are longitudinal, and if the direction of motion of the first few impulses is determined this fixes the azimuth. In the case of the earthquake of September 9, 1910, the beginning of the shock was quite distinctly registered by the N-S component seismograph, while the E-W component showed almost no trace of the first preliminary tremor; therefore the azimuth was N-S. The epicentral distance deduced from the record was such that the earthquake waves must have come directly over the north pole. This earthquake was identified with one reported from Unalaska.

In addition to the records of earthquakes the bulletin contains the result of a study of microseismic disturbances. From the seismograms for practically every day in the two years the mean period and amplitude of these disturbances was determined. The time of day selected was usually 7 a.m. The mean period varied from four to eight seconds, and the mean amplitude during the winter months varied from two to six or eight and occasionally ten microns, while in the summer months the mean amplitude was very much less, seldom going above two microns.

The pamphlet is illustrated by a beautiful seismogram for April 12, 1910, recording a distant earthquake, whose epicentral distance and azimuth located the earthquake on the Asiatic coast near Formosa.

For the rapid location of the epicenters of earthquakes two large maps were constructed and are published with the pamphlet.

F. J. ROGERS.

BEITRAG ZUR BESTIMMUNG DER FORTPFLANZUNGSGESCHWINDIGKEIT DER ERDBEBENWELLEN IN DEN OBERSTEN ERDSCHICHEN. By K. Hausmann. *Comptes Rendus*, International Seismological Association, 1912.

The conclusions of this paper are based on the results of the observations on a series of earthquakes which affected the region around Aachen during the year 1911. Several of these shocks occurred near the end of May, 1911, and one in the first part of September of the same year. These earthquakes all originated at comparatively shallow depths, and were all short sharp shocks. The intensity, though

varying somewhat in the different earthquakes, was slight. The shocks were felt by persons at rest but not by those in motion. Outside of a few cracks produced in buildings, no damage was done by the earthquakes.

The geological structure of the region in which the earthquakes originate is fairly well known. It consists of folded Paleozoic rocks which occupy an area having the form of a four-rayed surface. One main extension of this area lies parallel to the strike of the strata and runs southwest and northeast, and is about forty kilometers wide. Another extension of the area is nearly perpendicular to the first and runs northwest and southeast, and is about forty-five kilometers wide. In the first direction there are many planes of dislocation, but they are old and all movement on them has probably ceased. In the direction perpendicular to the strike of the rocks there is a system of dislocations on which movements have been in progress since Tertiary time. Movement on these dislocations is still in progress, as was indicated by recent measurements; and it seems probable that the earthquakes here in question originate on this system of fractures running northwest and southeast.

These earthquakes are particularly well adapted to a study of the velocity of propagation of earthquake waves. The position of the epicenter of the earthquakes is fairly well known, and there are many seismographic stations in the region lying round about. Further, the sharpness and definiteness of the earthquakes render the interpretation of their seismograms and the determination of the time of transit of the waves of different phases a fairly easy matter.

The writer gives a table which shows, for several stations situated at varying distances and lying in various directions from the epicenter: first, the distance of the earthquake epicenter from the observing station; and second, the time of arrival of the waves of each phase, where that could be determined. Curves are also shown which give a graphical assemblage of the observed facts.

He concludes from his work that the velocity of propagation of the earthquake waves in the upper strata of the earth's crust is dependent not only upon the nature of the rock but also upon the arrangement of the strata. In this particular region it is found that the first preliminary tremors which have traveled in the direction of the strike of the rocks, have an apparent velocity of 6.0 kilometers per second for distances which range from 150 to 200 kilometers. With increasing distance of the observing station from the epicenter the apparent velocities increase

slightly until they reach a value of 6.7 kilometers per second for distances of 400 kilometers. For waves traveling in directions transverse to the strike, the apparent velocities of the first preliminary tremors were found to be 5.0 kilometers; and 5.5 kilometers per second for distances of 150 kilometers and 400 kilometers, respectively. The second preliminary tremors travel somewhat more slowly in the direction of the strike than transverse to it. When traveling parallel to the strike they have a velocity of 3.4 kilometers per second where the distance is between 150 and 200 kilometers, and at distances of 300 kilometers the apparent velocity is found to be 3.6 kilometers per second. If the direction of propagation be transverse to the strike the corresponding values are found to be 3.5 and 3.6 kilometers per second.

The apparent velocity of the surface waves, as determined at various stations, appears to vary in an irregular manner, so that no definite rule could be found. The mean velocity appears to be about 3.3 kilometers per second.

An examination of the times of transit of main waves, as given by the writer in the table, reveals the fact that the velocity of the surface waves in some cases was as low as 2.5 kilometers per second and in another case as high as 3.9 kilometers per second, though in every case the values calculated from the observations of different earthquakes at the same station agree fairly well.

The results of the above described investigation are of great interest in connection with the very important problem of determining the distance and position of the epicenter of a near shock from a given observing station. If the values derived from the observations of these earthquakes at Aachen be accepted, the need for caution in the application of formulae is at once apparent. The formulae which are used in determining epicentral distances are employed upon the assumption that, for all earthquakes whose epicentral regions lie at the same distance from the observing station, the time of transit of the waves of the first preliminary phase will be the same, and also that the time of transit of the waves of the chief phase will be constant. The observations in question indicate that the first preliminary tremors may show a considerable variation in their velocity of propagation, and that the velocities of the main waves may vary in an even greater degree. The value of $L - P$ upon which the formulae depend will vary in a very irregular manner with marked variations in the velocities of the first preliminaries and the main waves.

The possibility suggests itself that it may not be possible to apply in one district the formulae derived from observations in another, since difference of material and structure will possibly affect the results to a considerable degree. In this connection it is interesting to calculate, from the time interval $L - P$ given in the above mentioned table, the distance of the epicenter, by the use of Omori's formula:¹

$$x^{\text{km}} = 7.27 y^{\text{sec}} - 38^{\text{km}}.$$

In some cases the results are found to agree fairly well with the well known values of epicentral distance, but in others, notably in the case of the Paris Station, there is a considerable discrepancy.

E. F. DAVIS.

PUBLICATIONS RECEIVED

The Seismological Society of America makes no exchanges.

Books and papers for review should be addressed to the chairman of the publication committee, J. C. Branner, Stanford University, California.

G. Agamennone.—Il terremoto del 24 Gennaio 1912 nelle Isole Jonie e sua velocità di propagazione. Rendiconti dalla R. Accademia dei Lincei, XXI, 646-652. Roma, 1912.

G. Agamennone.—Il disastroso terremoto nel bacino occidentale del Mar di Marmora. Est. dalla Revista di Astronomia e Sci. affini, VI, Torino, 1912.

Boldi, Marc' Aurelio.—Conferenza sul materiale di legno rinforzato, cementato e protetto. Roma, 1912.

Otto Klotz, LL.D.—Seismology, terrestrial magnetism and gravity. Report of the Chief Astronomer, Department of the Interior, Ottawa, Canada, 1912.

E. Tams.—Die seismischen Registrierungen in Hamburg vom 1 Januar 1909 bis zum 31 Dezember 1909. Jahrb. der Hamburgischen Wiss. Anstalten XXVII, Hamburg, 1910.

J. B. Woodworth.—Harvard Seismographic Station: fourth annual report for the year 1 August 1911 — 31 July 1912. Cambridge, 1913.

Galdino Negri.—Sobre algunos elementos sismicos de los terremotos sud-andinos. Boletin de la Sociedad Sismologica Sud-Andino, 1912. San Juan, 1913.

¹ Publications E. I. C., 1913, 18, 90.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF
THE SEISMOLOGICAL SOCIETY OF AMERICA

February 4, 1913

The meeting, held in Room 332, Geology Building, Stanford University, Cal., was called to order by the Secretary, and Dr. Branner was elected chairman. Directors Branner and Townley were present and Directors Bauer, Burckhalter, Derleth, Louderback, McAdie, Marvin, von Geldern and Woodworth were represented by proxies.

The minutes of the meeting of the Board of Directors held on November 30, 1912, were read and approved.

The following named persons were duly elected to membership in the Society: Dr. B. Berloty, S. J. Saadnail by Beyrouth, Syria; Everette De Galyer, Tampico, Mex.; Edward Lynch, Berkeley, Cal.; Victor Ziegler, Rapid City, So. Dak.

The Secretary reported the resignation of five members, and Dr. Branner reported the death of one member, Mr. H. E. Kramm of Ithaca, N. Y.

A Nominating Committee and a Board of Election were appointed, as follows:—

NOMINATING COMMITTEE

G. D. Louderback (chairman),
B. A. Baird,
F. H. Fowler,
D. S. Richardson,
J. A. Taff.

BOARD OF ELECTION

A. G. McAdie (chairman),
W. G. Reed,
W. S. Tangier Smith,
H. W. Turner,
L. Wagoner.

S. D. TOWNLEY, Secretary.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

- I. **Microseismic shock**: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
- II. **Extremely feeble shock**: recorded by several seismographs of different kinds; felt by a small number of persons at rest.
- III. **Very feeble shock**: felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- IV. **Feeble shock**: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.
- V. **Shock of moderate intensity**: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.
- VI. **Fairly strong shock**: general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.
- VII. **Strong shock**: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- VIII. **Very strong shock**: fall of chimneys, cracks in walls of buildings.
- IX. **Extremely strong shock**: partial or total destruction of some buildings.
- X. **Shock of extreme intensity**: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.



TAAL SEISMIC STATION

The Bulletin of the Seismological Society of America

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NO. 2

THE NEW SEISMIC STATION NEAR TAAL VOLCANO.

By M. SADERRA MASÓ

With the view of studying more closely the activity of this volcano and of being in a position to warn the people of any impending eruption, a seismological station has been established on the NNE shore of Lake Bombon or Taal, some five miles distant from the volcano. As is well known, the volcano is situated on an island near the center of the lake, the highest rim of the crater rising some 996 feet above the water of the lake, and about 1,000 feet above the level of the sea, which is 4.3 miles beyond the SSW shore of the lake.

For the establishment of this station the Philippine Legislature made a special appropriation of \$9,000, the money being used to buy a suitable plot of ground and to erect a substantial reinforced concrete building, with its instrumental equipment.

The building is situated about twenty feet above the level of the water, and thus commands a view of the lake and of the volcano; and being located near the ridge of a fault which radiates from the volcano in a nearly SW-NE direction, it is expected to be very favorable for the registration of the slightest shocks having their origin in the volcano.

The instrumental equipment of the observatory is as follows:

Meteorological—Mercurial barometer, one Richard's barograph, maximum and minimum thermometers, wet and dry bulb thermometers, a Richard's psycrograph, a quadruple anemometer, registering the direction and velocity of the wind, rainfall and sunshine.

Seismological—A Vicentini microseismograph and an Agamennone seismograph. The Vicentini was selected for the station on account of the satisfaction which the one installed in the Manila Observatory gave during the last eruption of the volcano. The Agamennone seismograph was added to record the stronger and more perceptible shocks.

Miscellaneous—A Friez improved water stage register; a set of underground thermometers, for use on the island of the volcano; two small deep-sea sounding thermometers, to locate some of the submerged steam vents which are supposed to exist around the volcano.

The station has, moreover, been provided with a fine motor launch, so that the volcano can be visited at regular intervals to watch its activity, and, in case of need, to transport the people of the towns around the lake, should there be another eruption; and also to carry visitors to the volcano.

The first idea was to place the station on the island of the volcano itself, but this plan was not feasible on account of the broken and unstable character of the ground, which consists chiefly of sand and lapilli, for the volcano has never ejected true molten lava. The approximate co-ordinates of the new station are $121^{\circ} 4' E$, $14^{\circ} 5' N$.

EARTHQUAKES AND RAINFALL.

By R. W. SAYLES

Since the eruption of Mount Pelee, Martinique, in May, 1902, I have been working at intervals on the subject of earthquakes, volcanoes, and the weather. The spring of 1902 was unusually cold and rainy in New England, and it was this condition of the weather associated with the volcanic phenomena which led me to the investigation. Earthquakes were studied with the volcanoes. For a long time nothing but the temperature element of the weather was taken. It appeared that about the time of eruptions or earthquakes there was a drop in the temperature, but on account of many exceptions to this rule the matter was dropped.

As I had not come to any decisive results with volcanoes, earthquakes, and temperature, it seemed best to try earthquakes and rainfall, on account of the larger annual variation in rainfall as compared with temperature. In December, 1911, therefore, I made a curve of the daily rainfall of the United States for the years 1904-05, and also made a daily earthquake curve for the same years, using the very complete catalogue of the Strassburg Seismographic Station. Only the shocks actually felt were used in the preparation of these curves, so those originating far from human habitations and far from lands under the oceans are not included.

As far as this work on the earthquakes of the world and rainfall of the United States has gone, I agree with Professor Drake very closely on his earthquake and rainfall discovery.¹ For 1904-05 the minimum of earthquakes and the minimum of rainfall comes in the winter months. For the summer months of 1904 the earthquakes and the rainfall were at a maximum. For the summer of 1905 the greatest number of earthquakes and maximum of rainfall came in July. The fall months, however, of this year have as a whole more earthquakes than the summer months, but very few more.

Comparing earthquakes and rainfall for the years 1904-05 another

¹ Noah Fields Drake: "Destructive Earthquakes in China," *Bulletin Seismological Society of America*, 2, 40-91; 124-133.

interesting fact is brought out. In 1904 the number of great shocks for the earth (shocks of intensity VIII or above Cancani scale) was 32 and the rainfall for the United States as a whole was approximately 23 inches. In 1905 the number of great shocks for the earth (shocks of intensity VIII or above, Rossi-Forel scale) was 62, while the rainfall was approximately 30 inches. With due allowance for the more complete data of 1905 as compared with that of 1904, there is too much difference here in the number of great earthquakes to be explained by any difference in completeness of records.

The rainfall curve of the United States was obtained by taking twenty continental stations as nearly equidistant as possible, adding the daily precipitation of all and finding the average. The curve which comes from this method when computed by months instead of days is almost a duplicate of that obtained by Professor Drake for continental China.

The table below is a recapitulation by months of earthquakes of the world and rainfall of the United States for the year 1905. Small shocks are those of intensities I-IV; moderate shocks V-VII; heavy shocks VIII-X, on the Rossi-Forel scale of intensity. The data for 1904 which appear on this same table give merely the heavy shocks of the earth VIII-X, Cancani scale, and the rainfall of the United States. So far I have collected greatest daily intensity and all the major shocks for this year, and have paid very little attention to the smaller shocks.

Month	Small Shocks	Mod'rate Shocks	Heavy Shocks	Total	Rainfall, U.S., ins. 1905	Great Shocks 1904	Rainfall U. S. 1904
January	87	21	4	112	1.61	0	1.22
February	105	34	3	142	1.83	2	1.26
March	122	23	4	149	2.38	2	2.49
April	114	22	9	145	3.20	3	1.81
May	119	18	3	140	3.49	1	2.69
June	107	28	4	139	3.61	5	2.49
July	137	31	7	175	4.07	3	2.68
August	116	21	4	141	2.20	6	2.52
September	118	18	9	145	2.62	2	2.88
October	138	22	6	166	1.88	3	1.72
November	126	31	6	163	1.89	3	.57
December	126	18	3	147	1.83	2	1.54
	1415	287	62	1764	30.61	32	23.87

It is to be noted that in obtaining a record of felt shocks for the world, about five-sixths of the shocks so reported belong to the northern hemisphere. My results therefore apply rather to the northern hemisphere than to the world. In the incomplete condition of my work I have not separated the shocks of the two hemispheres, except in a rough way, to obtain an approximate idea of the ratio in each. The largest seasonal percentage of shocks for the southern hemisphere for 1905 came in the fall months.

A comparison of the earthquakes reported in the Strassburg catalogues with reports of earthquakes obtained here and there previous to the foundation of the Strassburg bureau makes it clear that all previous reports were very meagre and fragmentary. Even with the splendid information supplied by the Strassburg catalogue it is not possible to know the whole truth concerning the degree of seismicity. It is almost certain that not more than one-fifth of the total earthquakes are reported in these catalogues, and that we shall never know how many earthquakes occur on the earth in any year. A study of these catalogues, however, appears to reveal the fact that in years in which there is a large number of shocks of intensity VIII-IX, Rossi-Forel scale, reported, the total number of shocks for the year is also large; and conversely, when there is a smaller number of great shocks reported the total number of shocks is smaller. A large number of great shocks would not only be followed by a large number of aftershocks, but such great shocks would also start off earthquakes which otherwise might not have come for months or years.

Realizing the hopelessness of obtaining anything like full data, and yet not wishing to give up the study of earthquakes and rainfall, I tried the following experiment. First the rainfall of the United States was obtained from 1871 to 1908. This result was reached by taking one hundred selected stations and finding the average of the whole for each year. The stations chosen were those which came the nearest to the average of the climatological section in which the station occurred. In this way a result was obtained which gives the actual conditions as nearly as possible. In view of the fact that Brückner found his climatic cycle applied to the whole earth, it is not unreasonable to compare earthquakes of the world and rainfall of the United States.

From a study of the curve which has resulted from this method, it appears that from 1872 to 1888 the rainfall of the country was above

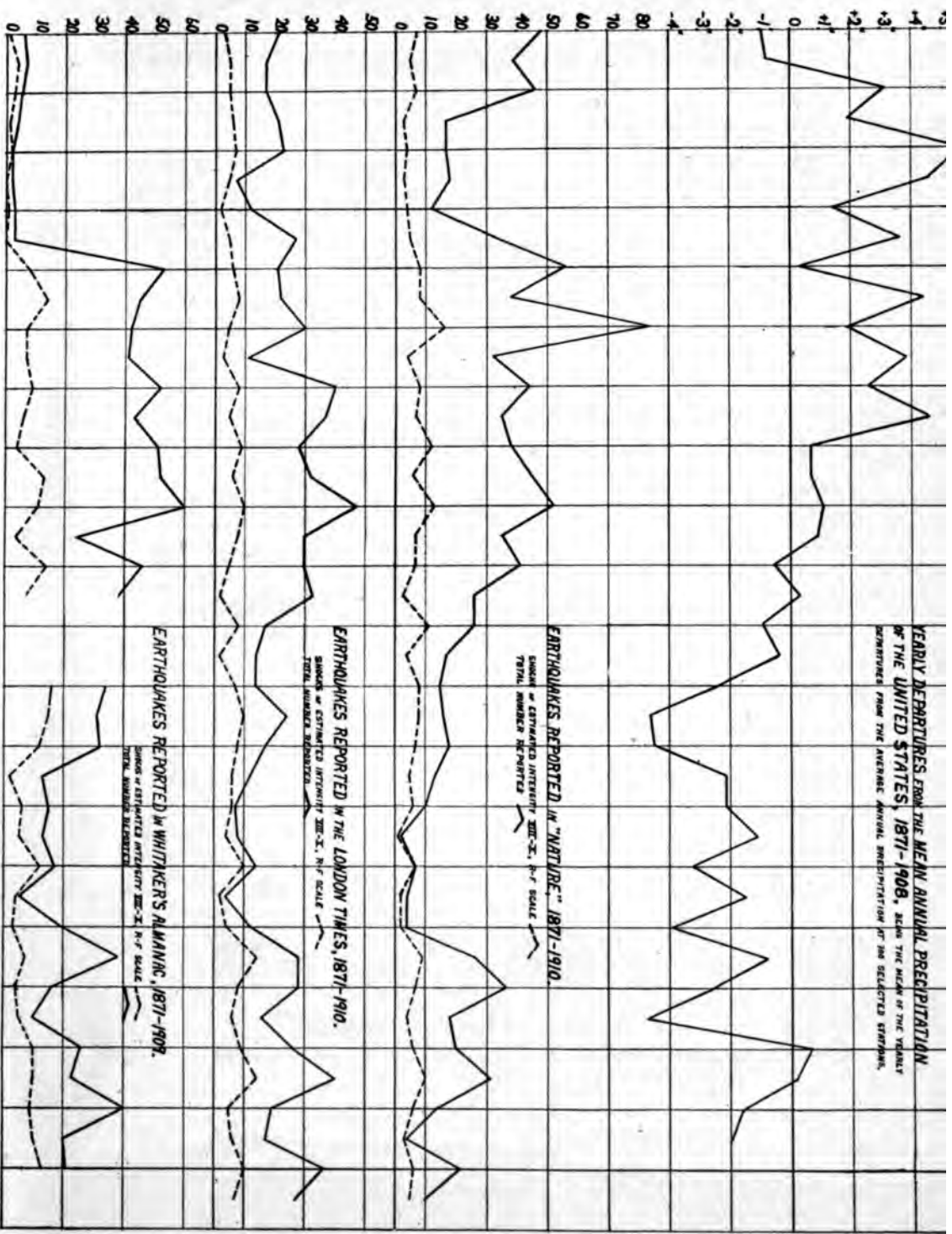
the normal, and that from 1889 to 1904 the rainfall (with the exception of one year, 1890) was below normal. This result appears to agree with Brückner's climatic cycle of an average of thirty-five years.²

For a large list of earthquakes of anywhere near a regular nature I was in despair. The lists containing the largest number of earthquakes were either for periods antedating my rainfall data or for a few years only in any one locality. To find a fairly full list for the earth covering the years 1871 to 1908 was out of the question. The method which I then pursued was to choose several reliable publications in which were recorded each year a list of reported earthquakes. Finally three were found which had reports for the years in question: *Nature*, the *London Times*, and *Whitaker's Almanac*. The first two had fairly constant reports, but *Whitaker's Almanac* had almost nothing from 1871 to 1878, and nothing for the years 1891-1892. By taking the reports of earthquakes given in these publications some idea may be gained of the seismicity of the earth. An inspection of the three earthquake curves shows a decided decrease in earthquakes between the years 1890-1901. If there had been more shocks than the normal during any of these last years, it is not likely that the reports would have been so meagre as compared with the reports for the years 1877-1889. The facilities for communication, especially by the submarine cable, increased by leaps and bounds during this whole period. In 1864 there were, according to the *Scientific American*, 52 cables, and in 1912, according to the *World Almanac*, there were 2554. If such increased facilities for communication affected the results, there should be a gradual increase of reported earthquakes for all the curves, but this does not appear.

Now all the curves shown, including the rainfall curve, begin to decline together about the year 1889-90, and all commence to rise again about the year 1902. For individual years there appears to be a lagging between the rainfall and the earthquakes of about a year, heavy rainfall often preceding a year of heavy shocks.

In a general way all four curves vary together in a remarkable manner. Many will question the whole result on account of the small amount of earthquake data, and some will say that the relation is a coincidence, and that the rainfall and earthquake curves merely *appear*

² E. Brückner: "Zur Frage der 35-jährigen Klimaschwankungen," *Petermanns Geographische Mitteilungen*, 48, 173-178, 1902.



RAINFALL AND EARTHQUAKE CURVES



to be on the same period. The shortness of the time taken makes any definite conclusion impossible. It appears to me, however, that the result obtained, especially in view of Professor Drake's work on the earthquakes and rainfall of China, is worthy of consideration and should not be cast one side without suspension of judgment.

If, as Professor Drake thinks, minor variations in rainfall and barometric pressure act as "trigger-pullers" for earthquakes, an ice sheet of a glacial period might have a more direct action and become a true cause. It is well known that all the glacial periods of the past were closely associated with periods of great diastrophism: Huronian, Cambrian, Permian, Pleistocene, and perhaps others, such as the Devonian and late Cretaceous. But although all the great glacial periods of the past have been associated with diastrophism on a large scale, it has not yet been proved that all the minor periods of mountain building have also been accompanied by precipitation on even a moderate scale. The difficulty in the preservation of ancient glacial beds, however, has been fully considered by Croll and others, and is well known. There is probably some other great cause for the larger movements in the earth. The shifting of so great a weight of water from the oceans to the continents, however, should require readjustments of no small order.

I can speak with authority on one case only of the pre-Pleistocene glacial periods. In the Roxbury conglomerate near Boston, Mass., Dr. Laurence La Forge and the writer found a thick bed of tillite. All the characteristics of true till are present. Without determining fossils it is not possible to say decisively that this formation is Permian, but its almost continuous position with the Carboniferous beds of the Norfolk basin and Permian of the Naragansett basin, to say nothing of the great lithological similarities with portions of these two, make it certainly of Permo-Carboniferous age.

The Roxbury conglomerate was deposited in a time of great volcanic activity, as evinced by intercalated lava flows and dikes of melaphyr. The tillite bed is near the top of the formation and is overlain by a bed of coarse gravel and sand, about fifty feet thick. Above this comes a thick bed of slate, probably indicating subsidence of the area.³

³ Robert W. Sayles and Laurence La Forge: "The Glacial Origin of the Roxbury Conglomerate," *Science*, N. S., 32, 723-724, Nov. 18, 1910.

The recent work with seismographs has revealed facts which cannot be ignored: Movements of the crust felt for some miles from the coast due to the incoming and outgoing of the tides; sinking and rising of the crust under high and low pressure barometric areas; the transmission of microseisms through the crust caused by the breaking of waves on the coasts. The earth is not as rigid as has been thought, but apparently in extremely delicate equilibrium.

This article has not been published in a dogmatic attitude, but merely to make public the results obtained, leaving to future research any decision on the question of a relation between earthquakes and rainfall. It would seem, however, to me that Professor Drake has taken a long step in a positive direction on this subject, and a step which cannot be ignored, covering as it does four thousand years of human history.

I wish to acknowledge the great assistance Mr. Burton M. Varney, Assistant in Meteorology at Harvard University, has given me in the collection of the rainfall and earthquake data, the basis of the curves shown in this article.

THE NEW MADRID AND OTHER EARTHQUAKES OF MISSOURI.

By F. A. SAMPSON

Slight shocks of earthquakes are not uncommon in the United States, but the three most prominent have been New Madrid, Charleston and San Francisco. Had New Madrid been a city like either of the others, the earthquake there would have been the best known and the most terrible of the three.

New Madrid was on the Mississippi river, sixty miles south of the junction of the Ohio and the Mississippi. A trading post was started in 1783 by Francois and Joseph Le Sieur, and in 1788 General Morgan of New Jersey laid out a pretentious town there. In 1811 it was a large town, St. Louis being the only larger one in what is now Missouri.

The settlement at La Petite Prairie (Little Prairie), was begun in 1794, by Francois Le Sieur, a little below the present town of Caruthersville, in Pemiscot county, and about thirty miles below New Madrid. In 1803 the village had 103 inhabitants, and continued to increase until the earthquake almost entirely destroyed it. Its site was long since carried away by the Mississippi river.¹ McBride found there some twenty houses, and a settlement extending six or eight miles back from the river.

The country affected by the earthquake extended from the mouth of the Ohio to the St. Francis river, a front of three hundred miles or more. In this territory the effects were so great that they were still visible a half century later, and in lesser degree they were felt even to the Atlantic coast.

There is a general popular belief of a close connection between volcanoes and earthquakes, but many noted earthquakes have occurred far distant from volcanoes. Those of Calabria, of Cutch, of Charleston, of the Riviera, as well as that of New Madrid were not in volcanic regions. Others have occurred at the same time as violent volcanic eruptions, sometimes in the same part of the country, and sometimes

¹ "History of Southeast Missouri," 300. Chicago, 1888.

at a distance without occurring at places near by. The night that was conspicuous for subterranean thunder at New Madrid was the same time as the fearful Caraccas earthquake, where thousands of the people were crushed beneath the ruins of their stone houses, although the concussions were probably not more violent than in the Mississippi valley.² Humboldt states that the shocks at New Madrid were the only examples on record of the ground quaking almost incessantly for three months at a point so far from an active volcano.

As the country was so sparsely settled at the time of the earthquake, it would not be expected that as full accounts of it would be preserved as from a well settled locality; but the State Historical Society of Missouri is fortunate in having in its library the statements given by many persons who experienced the earthquake, or by persons who soon after visited the locality and recorded the accounts of those who were witnesses of the events narrated by them. This paper is written from such records,—those that can be rated as original sources of information. There are accounts of the earthquake in various books, magazines and newspapers, that are not here quoted, as they generally do not refer to authorities for what they tell; this is especially noticable in an account published in *Popular Science Monthly*, and written by one connected with the United States Geological Survey, in which no authority is given, and of the only quotation made, it is not stated from whom it is taken.

Among perhaps the most competent observers of the earthquake was John Bradbury, an Englishman then traveling in this country, who arrived at New Madrid by boat on the evening of December 14, 1811, and the evening of the next day reached Devil's Channel, below the upper Chickasaw bluffs, where the boat tied up at a small island, and where he first experienced the earthquake.³

L. Bringier was near New Madrid, traveling on horseback at the time of the earthquake, and soon after wrote of it.⁴

Col. John Shaw was thirty miles north of New Madrid at the beginning of the earthquake, and was for days a witness to what he recorded.⁵

William Leigh Pierce was on a boat from Pittsburg to New Orleans, entered the Mississippi December 13th, and on the evening

² Flint. Hildreth.

³ See Bibliography No. 1. (At end of article.)

⁴ Ibid., No. 3.

⁵ Ibid., No. 16.

of the 15th tied up to the shore below New Madrid, at a point which he states was 116 miles from the mouth of the Ohio, but was probably less than that. In a letter written from "Big Prairie," dated December 25, 1811, to the *New York Evening Post*, he gave an account of the earthquake. This letter and a later one, with letters from two other persons to other papers, were published in a pamphlet at Newburyport, Massachusetts.⁶

Eliza Bryan lived at New Madrid before and during the earthquake, and in a letter dated March 22, 1816, to Rev. Lorenzo Dow, the evangelist, she gave an account of her experiences in it.⁷

James McBride, with others, was taking supplies from Ohio to New Orleans, by two boats. The first shocks occurred while they were in the Ohio river. When they reached New Madrid they moored their boats where a part of the town had been, but which was now a part of the river, and coffins were exposed along the bank. He went on shore with difficulty, and went some two miles back from the river. All the houses, although built of logs, were prostrated or nearly overturned and wrecked. He found three Frenchmen who were sheltering themselves by some boards taken from the buildings, and they were the only inhabitants left. On April 1, 1812, he wrote to his aunt in Pennsylvania, from a place above Natchez.⁸

Dr. Foster while traveling on the Mississippi met a Mr. A. N. Dillard, who lived near New Madrid and who was a witness of the earthquake, and related to him his experiences and observations in it; and Foster also visited the locality and talked with other persons.⁹

Dr. Hildreth's account of the earthquake was given him by one who at the time of its occurrence was about forty miles below New Madrid, on a flat boat on his way to New Orleans.¹⁰

Professor Broadhead's account of the earthquake is made up largely of quotations from the publications mentioned in the accompanying bibliography.¹¹

Timothy Flint was not in the earthquake, but he and his family spent the winter of 1819-20 at New Madrid, where he talked with many persons who related the facts, and his account is from what he saw and heard.¹²

Michael Brounm lived in Pemiscot county a half mile from the

⁶ Ibid., No. 14.

⁷ Ibid., No. 5.

⁸ Ibid., No. 11.

⁹ Ibid., No. 7.

¹⁰ Ibid., No. 8.

¹¹ Ibid., No. 4.

¹² Ibid., No. 6.

center of disturbance, and his account is given in the history of an adjoining county.¹³

Godfrey Le Sieur, the son of Francois Le Sieur, the founder of Little Prairie, was in the earthquake, and he wrote an account of it in 1871 to Prof. A. D. Hagar, formerly State Geologist of Missouri.¹⁴

Sir Charles Lyell visited New Madrid and vicinity in 1846, and conversed with many persons who were there during the earthquake. He visited the former Lake Eulalie, and talked with Mr. W. Hunter, the owner of it.¹⁵

Wetmore gave an account of a Mr. Walker, a "field naturalist," accompanied by a Frenchman of Little Prairie. His account, in part at least, was doubtless also derived from other persons who were in the earthquake.¹⁶

"Fagots from the Camp Fire" was an account of the earthquake as given to the author by a woman whose father was in the earthquake; but the account bears evidence of having been made up rather by the author than by the widow whose hospitality he was sharing during the Civil War; but at the same time he was thinking more of his belief that she was scheming to have him captured by the Confederates than of recording the story of this earthquake.¹⁷

Rozier, in his "History of the Early Settlements of the Mississippi Valley," has the accounts as given by Lewis F. Linn, Henry Howe in his "Great West," and Le Sieur.¹⁸

John J. Audubon, the naturalist, at the time of the earthquake was traveling in Kentucky on horseback; and in his journal tells of his experiences.¹⁹

Professor Shepard's theory of the cause of the earthquake will be noticed later.²⁰

The first shock of the earthquake was at two a.m., of December 16, 1811.²¹

A half hour after the first shock there was another as severe, and others followed six to ten minutes apart, and by daylight twenty-seven shocks had occurred. In the morning several more severe shocks occurred, and on the 17th three more severe ones, at 5, 7, and 12 o'clock.²²

¹³ Ibid., No. 2.

¹⁴ Ibid., No. 9.

¹⁵ Ibid., No. 10.

¹⁶ Ibid., No. 17.

¹⁷ Ibid., No. 20.

¹⁸ Ibid., No. 21.

¹⁹ Ibid., No. 19.

²⁰ Ibid., No. 22.

²¹ Le Sieur. Bryan. Bradbury. Hildreth. Dillard. Pierce says about midnight. Shaw says 2 a.m., Dec. 14th.

²² Bradbury.

Lighter shocks were felt afterwards till January 23d, when there was one as violent as any.²³ The earth was in continual agitation, visibly waving as a gentle sea until February 4th; and on the 7th at 4 a.m. one more violent than any which had preceded, and which was called the "hard shock."²⁴ And this was so severe as far away as St. Louis that fowls fell from the trees and crockery fell from shelves. Miss Bryan, writing in March, 1816, said the shocks had continued to that time, and that during the preceding winter two had occurred that were more severe than any others had been for two years previously.

Jared Brooks, at Louisville, seems to have kept an account of the number of shocks felt at that place, and to have divided them into six classes according to intensity, and in the thirteen weeks following the first shock he recorded eight of the greatest severity, ten of the second class, and in all a total of 1874 shocks.²⁵

A letter in the *Louisiana Gazette* from Cape Girardeau, dated February 15, 1812, stated that the shock of February 7th at that place was more violent than that of December 16th, and lasted longer, the earth being in constant motion for an hour. Considerable damage had been done to buildings in the town.²⁶

The shocks were easily distinguished into two classes: those in which the motion was horizontal, and those in which it was perpendicular. The latter were the ones that were attended with the explosions, the terrifying noises and the engulfing waters; but they were not so destructive as the others.²⁷

The shocks sometimes came on gradually, and finally culminated; again they would come without premonition and with terrific force, and then gradually subside.²⁸ Bradbury said the shocks came from a little northward of east and proceeded westward, while others say they came from the west or southwest.²⁹

The noise was described as "inconceivably loud and terrific";³⁰ as distant rumbling sounds succeeded by discharges as if a thousand

²³ Bryan. Colonel Shaw does not mention any shocks between the first one and this one, which he says was at 2 a.m., and that it was the greater shock.

²⁴ Bryan. Le Sieur says that one made deep lakes of high land.

²⁵ Bibliography No. 12. Pierce gives a list of eighty-nine shocks from the 16th to the 23d, but also mentions that on the 17th there was a continued series of shocks with very little intermission.

²⁶ "History of Southeast Missouri," 307. Chicago, 1888.

²⁷ Flint. Lyell.

²⁸ Foster.

²⁹ Dillard. Le Sieur.

³⁰ Bradbury.

pieces of artillery were suddenly exploded;³¹ or as loud but distant thunder, and more hoarse and vibrating;³² a noise with the accompanying crashing of trees, the tottering and shaking of the earth so that persons could not stand or walk;³³ these and the bursting of the ground not only frightened the people, in one case so badly as to cause the death of a woman, but so that birds and animals screamed in their fright, the cattle crowded around the assembled men for companionship and protection, and birds lost all power and disposition to fly, and they too sought the protection of man.³⁴

Accompanying the noise the whole land was moved and waved like the waves of the sea,³⁵ violently enough to throw persons off their feet, the waves attaining a height of several feet, and at the highest point would burst, throwing up large volumes of sand, water, and in some cases a black bituminous shale,³⁶ these being thrown to a considerable height, the extreme statements being forty feet,³⁷ and to the tops of the trees.³⁸

More than one account says that the water that was thrown up was lukewarm—so warm that in swimming or wading through it there were no chilly sensations.³⁹

With the explosions and bursting of the ground there were flashes, such as results from the explosion of gas, or from the passage of the electric fluid from one cloud to another, but no burning flames;⁴⁰ there were also sulphuretted gases, which made the water unfit for use,⁴¹ and darkened the heavens,⁴² giving some the impression of its being steam,⁴³ and so dense that no sunbeam could find its way through. With the bursting of the waves large fissures were formed,⁴⁴ some of which closed again immediately,⁴⁵ while others were of various widths,

³¹ McBride. Linn. Pierce.

³² Bryan. Le Sieur.

³³ Le Sieur.

³⁴ Bryan. Bradbury. Flint.

³⁵ Le Sieur. Linn. Walker. Brounm. Flint.

³⁶ Linn. Lyell. Bryan. Brounm. Dillard. Flint. Colonel Shaw said a hard, jet black substance, smooth as if worn by friction, and different from anthracite or bituminous coal.

³⁷ Dillard.

³⁸ Flint. Brounm. Le Sieur said six to ten feet. Pierce, who was on the river, says that the spouting from the river of water, mud, and sticks was thrown at least thirty feet high, and in places appeared "to rise to the very heavens." Large tree-trunks were also thrown up from the river.

³⁹ Le Sieur.

⁴⁰ Dillard.

⁴¹ Bryan.

⁴² Bryan. Brounm.

⁴³ Linn.

⁴⁴ Dillard. Le Sieur. Walker. Pierce.

⁴⁵ Bryan.

as much as thirty feet, and of various lengths.⁴⁶ These fissures were generally parallel to each other, nearly north and south, but not all.⁴⁷

In some cases instead of fissures extending for a considerable distance there were circular chasms, from five to thirty feet in diameter, around which were left sand and bituminous shale, which latter would burn with a disagreeable sulphurous smell.⁴⁸ Lyell mentions that the sand and lignite surrounding these cavities would not be enough to one-tenth fill them.

Lyell saw "the sink-hole where the negro was drowned." It was in a flat plain, with steep sides, and twenty-eight feet from the top to the water in it. Lyell was told that some of them had been "deep as wells," and Flint saw a hundred chasms that remained fearfully deep.

In cases where the explosion occurred under trees it was sufficient to split them through the center, even to forty feet high; and Foster at the time of his visit found such trees still standing, one part of the tree on one side of the fissure and the other part on the other side.⁴⁹

Dillard's grandparents had obtained a boat load of iron castings, which had been stored in a cellar. During one of the shocks the ground opened under the house, and the castings were swallowed up so that no trace of them was afterwards found.⁵⁰

The changes in elevation produced by the earthquake were very great, and extended for many miles. Before the earthquake New Madrid was fifteen or twenty feet above the summer floods, but it sank fifteen feet;⁵¹ a half mile below the town the banks of the river were not disturbed; and the beds of some of the lakes back from the river were elevated ten to twenty feet.⁵²

The Indians claimed that Seneca creek, Kinamore slough, Honey Cypress, Buffalo creek, Raglin and Taylor sloughs, which all run about the same direction, northwesterly and southwesterly, were originally large fissures and parallel with the smaller fissures of the earthquake.⁵³

⁴⁶ Dillard. Lyell. Le Sieur says running north and south parallel for miles—that he had seen them four or five miles long, four and one-half feet deep, and ten feet wide.

⁴⁷ Lyell says some were from ten to forty-five degrees west of north.

⁴⁸ McBride. Lyell. Pierce.

⁴⁹ Foster. McBride.

⁵⁰ Foster.

⁵¹ Bryan. Dunklin. Brounm.

⁵² Le Sieur. Rozier. Shaw says five or six feet.

⁵³ Brounm.

Lyell found the "sunk country" covered with trees standing but dead, many of them two hundred years old, and evidently killed by the loosening of the roots during the horizontal and continued undulatory motion of the ground. The descent into this sunk country he found in places to be as much as twenty to thirty feet. At Little Prairie these dead trees were standing in water.

He visited the former Lake Eulalie, accompanied by Mr. W. Hunter, its owner. It had been three hundred yards long and one hundred wide, of clear water and well stocked with fish. It was then covered with trees, all of different species from those on ground twelve or fifteen feet higher. The trees in the site of the former lake were less than thirty-four years old. He found two parallel fissures about eight yards apart by which the water had suddenly escaped. He does not say whether the bed of the lake had been elevated, but if not it is not shown why it did not again fill with water. Lyell says that the sunk country extended seventy to eighty miles north and south and thirty east and west.

When Foster visited the neighborhood he found large trees of walnut, white oak and mulberry which had been on high ground but were then submerged ten and twenty feet beneath the water, and cypress so far under water that he had paddled among the branches. At other places the subsidence had been so great that the tops of trees just appeared above the surface,⁵⁴ or, as at Reel Foot lake, were entirely below the surface.

Before the earthquake keel boats came up the St. Francis river, and again into the Mississippi river three miles below New Madrid, but this bayou was elevated so that it was dry.⁵⁵

The most notable of the new lakes formed by the earthquake was Reel Foot lake, across the river in Tennessee. This is sixty to seventy miles long, and three to twenty wide.⁵⁶ In some parts it is very shallow, and in others fifty to one hundred feet deep. Lofty forest trees sank down with the forming of the lake, and "disappeared in a sea that was broader and deeper than that of Galilee." Long afterwards the trees were to be seen still standing, branchless and almost or entirely covered with water.⁵⁷ The water of the lake is not the same as in the Mississippi, but is clear as mountain water, and not the yellow muddy water of the river.

⁵⁴ McBride.

⁵⁶ Brounm.

⁵⁵ Foster.

⁵⁷ Linn.

Le Sieur, writing in 1871, says the shocks had continued from 1811 to that time, less and less each year, and not violent enough to produce any change of surface.

All accounts agree that for a time the waters of the Mississippi "flowed up stream,"⁵⁸ caused by an elevation of the bed of the river and extending across it, so that the water rose to a considerable height. Many boats were forced into a creek above New Madrid, and when the mass of the waters finally tore away the obstruction, some of the boats were left stranded, and others shot down the river with great velocity. A few days' action of the powerful current was sufficient to wear away every vestige of the barrier.

No more startling change of scenery could well be imagined than that at old man Culberson's, who lived with his family in a bend of the Pemiscot river, ten miles below Little Prairie. There was about "an acre of ground" between his house and the river, and on it was his smoke house and well. On the morning of the 16th, Mrs. Culberson went out to get some meat from the smoke-house, but no well or smoke-house was to be seen. Upon search they were both found to be on the other side of the river. A fissure across the bend had been so large that the river flowed through it, and the great pressure on the isolated spot forced it to the opposite side of the river when the next earthwave occurred.⁵⁹

The St. Louis *Globe Democrat* of March, 1902, has an account of the disappearance of Island No. 94, taken from the papers of the late Aug. Warner. The island was not far from Vicksburg. Captain Sarpy of St. Louis with his family, and carrying considerable money, tied up at this island on the evening of December 15, 1811, but finding that a band of river pirates were waiting to rob him, he quietly dropped further down the river. The next morning he found the island had disappeared and the robbers had been swallowed up.

Numerous instances are given of the terror being so great that persons did not know what to do, but Wetmore tells of the Frenchman who did not allow himself to be overcome by what was surrounding him. When Mr. Walker felt the ground rock under his feet, and saw tall trees waving like spars of a ship on a stormy ocean, he sank to his knees in prayer for safety; but the Frenchman who was with him exclaimed, "Monsieur Valkare, no time to pray! Sacre Dieu! gardevous

⁵⁸ Lyell. Flint. Linn. Miss Bryan says for a few minutes.

⁵⁹ Southeast Missouri.

les branch!" and the falling branches of the trees adding effect to the exhortations, they made flight to the nearest prairie.

Miss Bryan wrote in 1816 that formerly they had been subject to very hard thunder storms, but for a year before the earthquake there had been none, and very few afterwards, and what there were resembled subterranean thunder.

In less than three months the people returned to their homes, and they became so accustomed to the shocks that "they paid little or no regard to them, not even interrupting or checking their dances, frolics and vices."

In 1820 passengers went ashore from a steamer at New Madrid, and feeling a house shake were frightened. The lady of the house said, "Don't be alarmed; it is nothing but an earthquake."

The persons who experienced the shocks generally did not theorize as to the cause, but Bradbury found a man near the Lower Chickasaw Bluffs who gave his theory. It was that a comet, which had appeared a few months before, had two horns, over one of which the earth had rolled, and was then lodged between them. The shocks were occasioned by the attempts to surmount the other horn. If this should be accomplished all would be well; otherwise inevitable destruction of the world would follow.

Bringier thought the cause was not volcanic, but was perhaps electricity. He thought the country was partly overlaid with driftwood at some distance below the surface; that this driftwood had become highly carbonized and reduced to a smaller compass, so that when the ground was disturbed by shocks it sank down.

James MacFarlane of Towanda, Pennsylvania, presented a paper to the American Association for the Advancement of Science holding "the Earthquake at New Madrid in 1811 probably not an earthquake."⁶⁰ His arguments were that the locality does not show any indications of volcanic action, and he thought the disturbance was from subsidence, due to solution of underlying strata. His evidence was the long continuance from 1811 to 1813; the progression from place to place, ending nearly one hundred miles from the place of beginning; that they were never repeated in the same place; that none of the ordinary phenomena of earthquakes occurred, except subsidence; that no great alluvial region like this has ever been visited by an earthquake; that earthquakes do

⁶⁰ Proceedings, 32d meeting, 1883. Same with discussion, *Science*, Sept. 7, 1883.

not occur so far from seashore; that the falling of the Wade farm of 500 acres on the shore of Reel Foot lake, in January, 1883, was a continuance on a small scale of the supposed earthquake of 1811-12. New Madrid and vicinity rested on tertiary or quaternary strata, and the subcarboniferous strata are on the borders of the depression, and older formations which were soluble were the underlying strata.

In the discussion Professor Cox declared there was no subcarboniferous in the vicinity, no caverns, no soluble limestone. The shocks were sudden. He had personally visited the locality, and found evidences of very great disturbances. Professor Nipher suggested that the position of the trees, whether upright or not, would help to determine. Some doubts were expressed whether there were any submerged trees, but Professor Cox said he had seen the trees still upright in the water.

Professor Marbut⁶¹ seeks to give a geological account of the swamp region or low lands of southeast Missouri, and this he does with only a slight reference to the earthquake, "the earthquake shocks of 1811 and 1812. A large part of the area is supposed to have sunk at that time, though the amount of the sinking has not been agreed upon. The relative effect of these two forces has never been clearly determined by even the most strenuous advocates of the earthquake's effectiveness."

The most satisfactory explanation of the results that were produced by the earthquake, that I have seen, is that by Prof. E. M. Shepard, of Drury College, Springfield, Missouri. While employed with the United States Geological Survey, he visited the region of the earthquake several times in 1904, for the work in which he was then engaged, that of the study of artesian waters. He found still apparent the effects of the earthquake, the fault scarps where the ground had sunk, the trees standing in Reel Foot lake with the tops below the surface of the water, and submerged trees at other places; the areas where the land had sunk, the trees killed, the depression partly filled with flood deposits, and then covered with a new vegetation different from the old; and great quantities of sand in places making the land barren, the sand found along the cracks and fault scarps, and in "sand blows" or low mounds of fine white sand mixed with lignite. He shows the geology of that part of the country, and that the Mississippi valley forms a strong artesian basin from the Tennessee mountains to the Ozarks; that beneath the loess of the surface there are 6 to 40 feet

⁶¹ Bibliography No. 13.

of gravel, followed by a layer of impervious blue clay, from 100 to 225 feet, then 10 to 40 feet of Orange sand, and under it the Silicious Claiborne or artesian sand 600 to 800 feet, and various other layers below, the subcarboniferous being 1300 to 2000 feet below the surface. At Memphis and at other points in a circle on the border of the sunken district, there are flowing wells. In these and in all the springs of the sunken area great quantities of fine sand are brought to the surface. This produces an undermining of the blue clay layer, and finally a readjustment of the strata affected. His conclusion is that whatever may have been the primary cause of the earthquake, the great local disturbance at New Madrid came from the artesian pressure from below undermining the superincumbent beds of clay, and that a slight earthquake wave would destroy the equilibrium of the region, resulting in the sinking of some areas and the elevation of others.

The writer has not had opportunity to get data of other earthquakes in Missouri, except of the two that follow:

EARTHQUAKE OF OCTOBER 7, 1857.

What seems to have been the most severe earthquake since 1811-12 occurred at St. Louis and other places in the Mississippi valley October 8, 1857.⁶² There were two shocks, the first about 4:15 a.m. and the other a few minutes later. Windows rattled, articles fell from mantels, the largest buildings were rocked to and fro, the river was in tumult, and animals were frightened. There was a great rumbling like the passage of a heavy vehicle over pavements, houses with walls even eighteen inches thick were violently affected, the motion being horizontal, the vibration being from east to west.

Some reports stated that the shocks were accompanied by a heavy mist or fog, but a dispatch from a place on the river below showed that the fog began there about eleven o'clock. At St. Louis the northern sky was clear, but the mist soon overspread the skies.

Dispatches from other points showed that the shocks were felt at many places in Illinois, and along the Mississippi river from Hannibal south, but at Hermann and Jefferson City there were no shocks felt. Accounts differed as to the direction from which the shocks came, but the *Democrat* reporter thought that the weight of evidence was that they came from the south.

⁶² *Missouri Republican*, Oct. 9, 1857. *Missouri Democrat*, Oct. 9, 10 and 12.

The Belcher well, which was then 2,265 feet deep, was not affected.

One person reported that he had seen a meteor as large as a full moon that shot across the sky south to north, and exploded with a loud noise; and one in Illinois said there was vivid lightning and loud thunder; but as these things were not mentioned by any other person there may be some doubt about them.

EARTHQUAKE OF OCTOBER 31, 1895

This was said to be the hardest shock since that of 1812. It was felt in seventeen states, and was most violent in a line extending south of the State of Ohio. Near Henson lake, six miles south of Charleston, Missouri, about four acres of ground were sunk and filled with water, forming another lake. Near Bertrand hundreds of mounds of sand were piled up, ranging from twelve inches to ten feet in circumference, and the ditches in this neighborhood were filled with water, coming from the holes made, there having been no rain to fill them in any other way for nearly two months. Near Big lake, four miles north of Charleston, were two small holes in the earth from which the water spouted to the height of three feet. In Dunklin county shocks were much lighter. It lasted three minutes from northeast to southwest, but no damage was done.⁶³

Bibliography of Original Source Material of the New Madrid Earthquake.

1. Bradbury, John, "Travels in the Interior of America in the Years 1809, 1810 and 1811," 207. Second edition, London, 1819. Thwaites' edition, "Early Western Travels," 5, 204.

2. Brounm, Michael. Account of the earthquake. "History of Dunklin County, Missouri, 1845-1895," 15. By Mary F. Smyth-Davis.

3. Bringier, L. Notices of the Geology of the Regions Around the Mississippi and its Confluent Waters—in a letter to Rev. Elias Cornelius. *American Journal of Science and Arts*, 1821, 3, 15.

4. Broadhead, Garland C. "The New Madrid Earthquake." *American Geologist*, August, 1902, p. 76. Also pamphlet reprint of same.

⁶³ *St. Louis Republic*, Nov. 2, 1895. "History of Dunklin County," by Mary F. Smyth-Davis, p. 18.

5. Bryan, Eliza. "History of Cosmopolite, or the Writings of Rev. Lorenzo Dow," 344. Eighth edition. Cincinnati, 1850.

Also in "History of Southeast Missouri," 304. Chicago, 1888.

6. Flint, Timothy. "Recollections of the Last Ten Years in the Mississippi Valley," 22. Boston, 1826.

His account is also given in Foster's "Mississippi Valley."

7. Foster, J. W. "The Mississippi Valley: Its Physical Geography," 18. Chicago, 1869.

8. Hildreth, Dr. Samuel P. "History of an Early Voyage on the Ohio and Mississippi Rivers, with Historical Sketches." *American Pioneer*, 128. Chillicothe, Ohio, 1842.

9. Le Sieur, Godfrey. "Letter to A. D. Hagar, former State Geologist of Missouri." *Campbell's Gazette of Missouri*, 394. R. A. Campbell, publisher. St. Louis, 1874.

10. Lyell, Sir Charles. "Second Visit to the United States of North America," 2, 172. In two volumes. New York, Harper and Bros., 1849.

11. McBride, James. "Down the Mississippi." *Quarterly Publication of the Historical and Philosophical Society of Ohio*, 5, No. 1. Jan.-March, 1910.

12. MacMurtrie, Henry. "Sketches of Louisville and its Environs"; added an appendix containing an account of the earthquakes experienced here from the 16th December 1811 to the 7th February 1812, extracted principally from the papers of the late J. Brookes. Louisville, 1819.

13. Marbut, Prof. C. F. "The Evolution of the Northern Part of the Lowlands of Southeastern Missouri." *The University of Missouri Studies*, 1, No. 3. July, 1902.

14. Pierce, Wm. Leigh, *et al.* "An Account of the Great Earthquake in the Western States, Particularly in the Mississippi River; December 16-23, 1811." Collected from facts. Newburyport, 1812.

15. Rozier, Fermin A. "Report on the Submerged Lands of the State of Missouri." *Proceedings of Southwestern Convention at Memphis*, November 1845. Also in *Western Journal*, 3, 391. St. Louis, 1850.

16. Shaw, Col. John. "New Madrid Earthquake." Account by —, *Second Annual Report and Collections of the State Historical Society of Wisconsin* for 1855.

Reprinted in *Missouri Historical Review*, January 1912, p. 91. Columbia, Mo.

17. Wetmore, Alphonse. *Gazetteer of the State of Missouri*, 131, St. Louis, 1837.

18. Linn, Lewis F., U. S. Senator. "Letter Relative to the Obstructions to the Navigation of the White, Big Black, and St. Francois." (To the U. S. Senate). Feb. 1, 1836.

Copied in *Wetmore's Gazetteer*, 134.

19. Shepard, Edward M. "The New Madrid Earthquake." *The Journal of Geology*, 23, No. 1, Jan.-Feb. 1905.

Also pamphlet reprint.

20. "Fagots from the Camp-Fire," by "The Newspaper Man," 179. Fourth edition. Washington, 1881.

21. Rozier, Firmin A. "Rozier's History of the Early Settlement of the Mississippi Valley," 198. St. Louis, 1890.

22. *Audubon's Journal*. His account is quoted in "Rozier's History of Early Settlement of the Mississippi Valley," 208; it is also given in St. John's "Life of Audubon," 33. J. B. Lippincott Co. (c. 1856).

SUDDEN EARTH-MOVEMENTS IN SUMATRA IN 1892.

By HARRY FIELDING REID

About 8 p.m. on May 17, 1892, a very severe earthquake occurred in northwestern Sumatra, which was particularly strong in the Residence of Tanpanoeli, and was even felt in the Malay peninsula 200 to 250 miles away. The intensity of the shock was so great that many landslides occurred in the mountain regions, and at Padang Si Dimpoean stone houses were so badly injured that they had to be torn down; and at various places wooden houses were thrown from their stone foundations. The surveys for the secondary triangulation of Sumatra were in the course of execution in the Residence of Tanpanoeli.¹ The monument of one secondary station was on the crater wall of the volcano Sorik Marapi. Landslides were especially marked on the slopes of this mountain, and the huts of Si Banggor, at its foot, were completely buried. A part of the inner crater wall fell in and a crack appeared close to the monument, which nevertheless remained perfectly vertical. For fear that the monument might not remain permanently in place, a second monument was built about three metres from the first; and its position was determined from the other stations. The three secondary stations, Sorik Marapi, Tor Si Hite and Sopo Oentjim, had been located with respect to the three primary stations, Goenoeng Malintang, Dolok Toedjoe and Dolok Maleja. (See map, figure 1.²) The new observations soon showed that Goenoeng Malintang, Sorik Marapi and Tor Si Hite had all been displaced; and the complete working out of the observations, in which observations from Tor Si Dohar Dohar were also used, gave the following displacements of these stations: (The direction of the

¹ J. J. A. Muller, De Verplaatsing van eenige Triangulatie-Pilaren in de Residentie Tapanoeli (Sumatra) tengevolge van de Aardbeving van 17 Mei 1892. *Verhand. d. Konik. Akad. van Wetensch., Amsterdam*, 1st section, 3d Pt., No. 2, 1895. Abstracts of this article are given in *Petermanns Mittheilungen*, 1895, 41, 97, 98; in *Nature* (London), 1895, 52, 129, 130; and in *Zeitschrift für Vermessungswesen*, 26, 129-135.

² This map was drawn from the map, figures and data of Captain Muller's article, loc. cit.

movement is given in degrees measured from the north around by east; the errors are the mean errors of observation.)

TABLE—DISPLACEMENTS AND MEAN ERRORS

Station	Amount (meters)	Direction
Sorik Marapi	1.23 ± 0.28	$344^{\circ} 57' \pm 14^{\circ} 30'$
G. Malintang	1.24 ± 0.34	$304^{\circ} 28' \pm 16^{\circ} 0'$
Tor Si Hite	0.64 ± 0.14	$149^{\circ} 2' \pm 17^{\circ} 45'$
Tor Si Manondong	$1.3 \pm$	?
D. Balamaja	$0.9 \pm$	?
Sopo Oentjim	$0.07 \pm$	16° ?

Before the earthquake, bearings had been taken on the two points, Dolok Balameja and Tor Si Manondong, only from a single station,

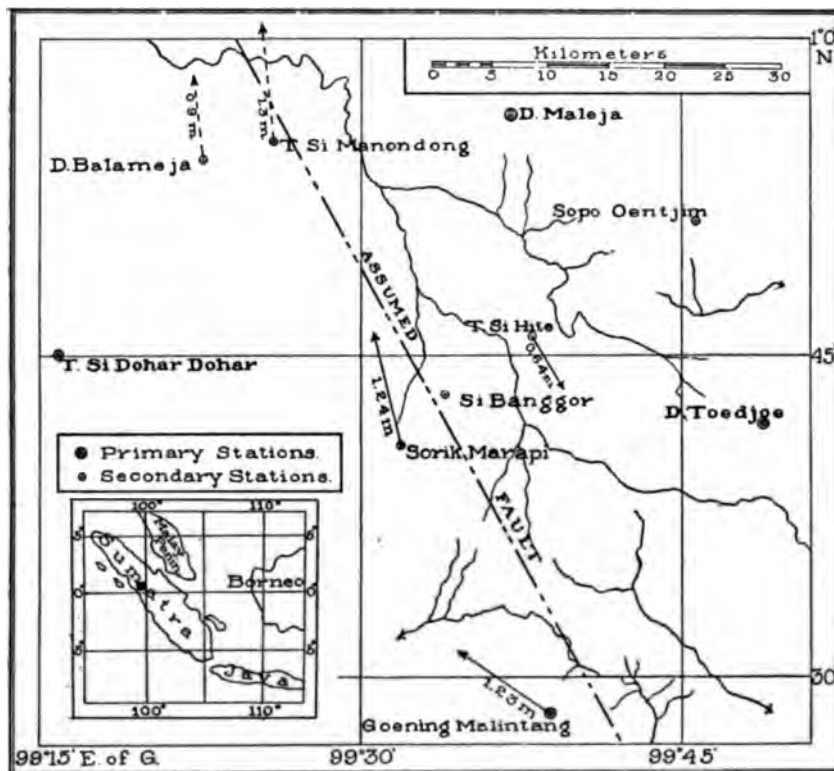


Fig. 1.

Dolok Maleja; afterwards bearings from the same station showed that they had moved, and that the component of their displacement in the direction indicated by the arrows was 0.9 and 1.3 meters, respectively. If these points moved in a somewhat different direction their displacements were somewhat larger.

The redetermination of the relative heights of the stations by vertical angles failed to show any change in the altitudes.

This was the first time that horizontal displacements of the earth, resulting from an earthquake, were established by geodetic measures; though it had long been known that sudden displacements were sometimes caused by earthquakes.

The displacements of these triangulation points were thus firmly established, but no attempt was made to explain what was the nature of the earth movements which they indicated. The results obtained from the study of the California earthquake suggested that the movements described above were the result of an elastic fling in opposite directions of the two sides of a fault, on which a rupture took place, which caused the earthquake; and after a few trials a position was found for a fault which would explain all the movements observed. This position has been plotted on the map, and trends about NNW-SSE. It will be seen that all the points to the left of this fault moved towards the northwest, and that the one point to the right of the fault, whose motion was definitely determined, moved towards the southeast. The amount of the displacement varied with the distance of

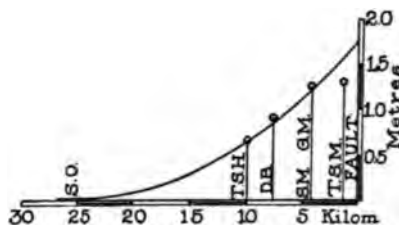


Fig. 2.

the station from the fault; the displacement being less as the distance was greater, as shown graphically in figure 2; there was no exception to this rule.

The displacement of Sopo Oentjim was calculated as only 7 cm.

and its direction a little east of north;³ which seems to indicate a displacement in the wrong direction; but it is well within the limits of errors of observation, and no reliance can be placed upon the result. If it is not entirely due to errors, the calculated movement is to be explained as follows:

The position of Sopo Oentjim was referred essentially to the two primary stations Dolok Maleja and Dolok Toedjoe. The former is near enough to the fault to have suffered a slight displacement towards the southeast, according to our hypothesis. Such a displacement could only have been discovered through a change in the direction of this station from Tor Si Dohar Dohar; as Captain Muller has not mentioned any change in this direction, it must have been insignificant. Nevertheless, though a displacement of Dolok Maleja of a few centimeters to the southeast might not be evident from so distant a station as Tor Si Dohar Dohar (it is more than 40 kilometers away), it may have taken place; and if it did, Sopo Oentjim would appear to have moved in the opposite direction. The slight approach of Dolok Maleja to Dolok Toedjoe would throw Sopo Oentjim apparently towards the northeast. Therefore the slight apparent displacement of Sopo Oentjim in this direction would really indicate a small displacement of Dolok Maleja toward the southeast.

The direction of the displacement of Goenoeng Malintang makes an angle of about twice its mean error with the direction of the fault, but this might readily be due to errors of observation; the direction of motion of Sorik Marapi and Tor Si Hite differ from the direction of the assumed fault line by less than their mean errors. The directions of motion of the two northwesterly stations were not determined; the observations only indicate that they moved in a general northerly direction. The directions of the displacements may therefore be considered as nearly parallel to the assumed fault.

The distribution of the displacement of the ground at the time of the California earthquake was determined from the displacement of thirty-four stations, which furnished a fair amount of data, and the position of the fault was well known;⁴ but in Sumatra the

³ By an error of lettering in the figure of the error-ellipses of Captain Muller's article, the direction of motion of this station is reversed, as appears from his text.

⁴ The California Earthquake of April 18, 1906, 1, 114-145; 2, 17-20.

movements of only three points were definitely, and two more partially determined; and the position of the fault had to be assumed. So that we cannot expect as concordant results in the latter as in the former case.

The attempt to explain the earth movements in Sumatra had reached this point before the geology of the island was looked up to see whether it supported or opposed the ideas advanced. It was found⁵ that the area under consideration lies in the volcanic zone which runs parallel to and not far from the southwestern coast of Sumatra, and that the structure lines of the region trend in a general NW-SE direction; though the geology of the region has not been carefully studied. A fault (called the Gadis-Ankola fault) lies about parallel with the Gadis river, which is represented in the map, figure 3, as running WNW. Another long fault lies to the northwest, and a number of shorter ones to the southeast. Two short faults, one near Padang Si Dimpoean, another to the southeast, lie about in the continuation of the fault we have assumed. It is to be noticed that the river Gadis is represented as flowing WNW, whereas its true course is NNW, as shown in figure 2. It is probable therefore that the Gadis-Ankola fault really trends NNW, and has the same trend as the assumed fault. Whether the Gadis fault or a neighboring one was concerned in the earthquake we are discussing, it is impossible to say; but the fact that it is possible to find a position for a fault which is in close harmony with the geological structure of the region, and which, by analogy with the California earthquake of 1906, explains all the displacements observed, both in direction and relative amount, makes it extremely probable that such a fault exists, and that the displacements were due to its rupture alone and the consequent elastic rebounds of its two sides. The fault could not have been confined to the seventy kilometers shown on the map; for the large displacement of Goenoeng Malingtang shows that it did not end there, but extended some distance further towards the southeast; and the great intensity of the earthquake at Padang Si Dimpoean, about fifty kilometers to the northwest and in the direction of the fault-line, indicates that the fault extended as far to the northwest as that

⁵ Wilhelm Volz, *Zur Geologie von Sumatra; Geologische und Palaeontologische Abhand. von E. Koken*, 10, Jena, 1902-1905. Figure 3 is copied from a part of a map in this article; its scale is one-fifth that of Figure 2.

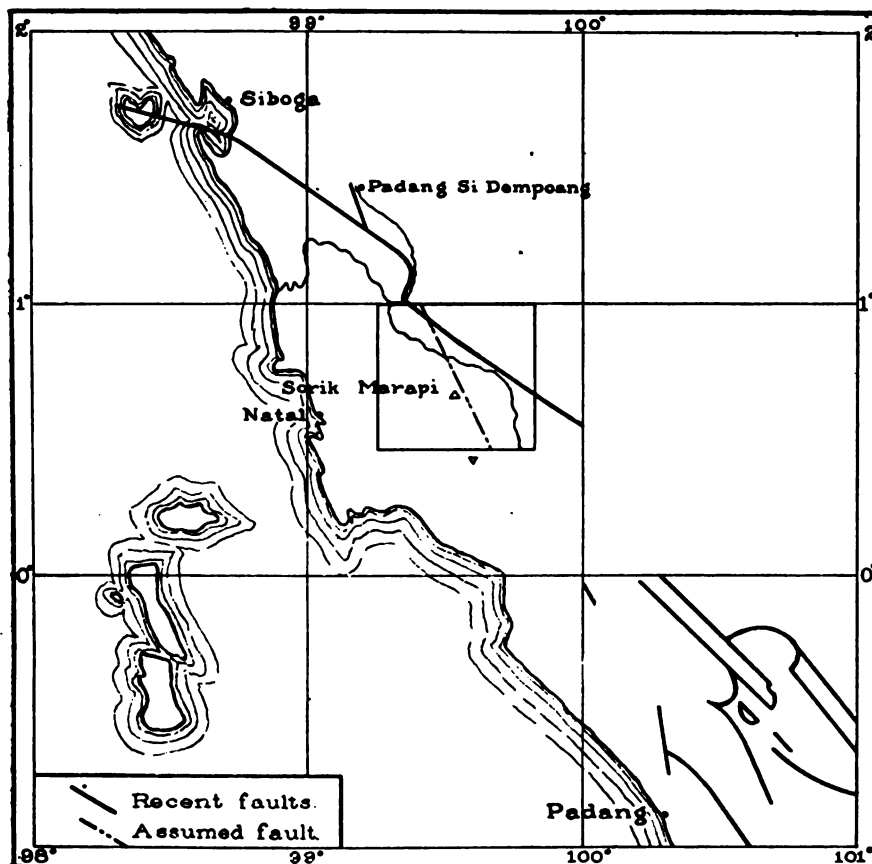


Fig. 3.

place, and probably further; so that it is not unlikely that the ruptured part of the fault had a length of 150 or 200 kilometers.

It must not be inferred that the fault was perfectly straight; it has been drawn so simply as an approximation; but nevertheless we must remember that faults with displacements parallel to the strike are apt to be straighter than those with displacements in the direction of the dip. For distances of tens of miles the San Andreas fault in California is nearly straight.

It is interesting to estimate the amount of slip at the fault itself. This can only be done in a very rough way. The greatest displacement measured is that of Tor Si Manondong, about 1.3 meters (see

figure 2); this station is about 2.2 kilometers from the fault; at the fault itself the elastic fling on each side was probably 1.7 to 2 meters, making the total relative slip of the two walls of the fault from 3.5 to 4 meters; which is not very different from the slip on the San Andreas fault at the time of the California earthquake.

The earth movements in California and Sumatra agree in that they were, in both cases, horizontal; that the slips on the faults were of the same order of magnitude, and that the sudden displacements were limited to zones of about the same breadth. These similarities probably all depend upon the dynamics of faulting. The further similarities, namely, that the two faults had nearly the same geographical direction, and that the southwestern sides of both moved relatively towards the northwest, must be accidental. The fault which caused the great Mino-Owari earthquake in Japan in 1891, also trended about NNW-SSE, but at the time of that earthquake the *northeastern* side moved towards the northwest.

There is one marked difference between the California and the Sumatra movements. In California stations on opposite sides of the fault, and not too near it, suffered a relative displacement of 1.8 meters between the earlier survey of 1874-1892 and that made immediately after the earthquake. In Sumatra no displacements are reported of the three primary stations, Tor Si Dohar Dohar, Dolok Maleja and Dolok Toedjoe, between the surveys made shortly before and immediately after the earthquake there. Dolok Maleja, the nearest of the three stations to the fault, is about eighteen kilometers from it. The different intervals between the surveys account for this difference in the two regions. The interval of twenty or twenty-five years between the surveys in California permitted the slow relative movement of adjacent areas (which set up the elastic strain, resulting in the earthquake) to produce a relative displacement of these areas, which the earthquake of course could not efface; whereas the very short interval between the surveys in Sumatra was not long enough for a measurable displacement of the outer stations to take place. In California the measured displacements on the western side of the fault were the sum of a slow movement and an elastic fling; in Sumatra the elastic fling alone was measured.

The difference just described supports the idea of slow displacements followed by rupture and elastic rebound, as opposed to the idea of sudden displacements of large areas.

Twenty years have passed since the Sumatra earthquake; if the slow displacements, which led up to it, have continued, and at a rate similar to that found in California, Tor Si Dohar Dohar and Dolok Maleja must have suffered a relative displacement of a meter or more at right angles to the line joining them. As they are about forty kilometers apart this would mean a change in the direction of the line joining them of about 5", an amount easily measurable. It would be of great interest from the standpoint of geophysics, and of importance for future surveys of this region, to determine this change of direction if it has occurred. For otherwise it will introduce the same kind of errors into future surveys, though on a smaller scale, that an unknown secular change in declination would introduce into magnetic surveys.

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AIR-BLASTS AND SHOCKS IN THE GOLD MINES OF THE KOLAR GOLD FIELD, MYSORE, INDIA.

By J. B. WOODWORTH

The report of Mr. W. F. Smeeth, the Chief Inspector of Mines for the State of Mysore in India, for the year 1911-12, contains some interesting information concerning air-blasts and quakes and the records obtained from the seismograph. In his report for 1908-09, the same writer distinguished air-blasts due to some condition of internal strain in the rock independent of superincumbent pressure, while the term quake was reserved for shocks occurring under circumstances which did not preclude the action of vertical pressure on pillars and portions of ground between stoped out areas.

It appears that in the Kolar gold field certain mines often experience severe local shocks, which cause much damage and no small loss of life.

The most disastrous shock known in this field in regard to the loss of life occurred on July 18, 1911. Fifteen persons were killed underground, six died in the hospital, three were seriously injured, seven were detained in the hospital, and twenty-five were slightly injured. The shock which caused this loss of life was strong enough to shake down plaster from buildings. Several levels were blocked in the mine by loosened rock and timber. In one level a tram truck was lifted bodily up 3.5 to 4 feet from the floor of the level, indicating an epicentral vertical movement beneath the mine. In one stope three pieces of timber were twisted into an oblique position by a movement of the footwall in a northerly direction. As a further illustration of the violence of the shock, it is stated that a coolie climbing up Rowe's shaft had reached a point thirty feet above the twenty-sixth level when the quake occurred. He was so stunned by the shock that he lost his hold of the ladder and fell to the plat below, and died later in the hospital. (pp. 35-36.)

In the case of the so-called air-blasts the period of vibration as recorded by the seismograph is said to be very short, the oscillations

of the ground being extremely rapid and giving rise to sounds and shocks which are often clearly perceptible, and sometimes causing damage to buildings.

According to the account of Mr. Henry M. A. Cooke, in charge of the seismographs, there have been installed one 80 kg. Wiechert horizontal seismograph and one Wiechert vertical seismograph. Owing to the intensity of the local shocks, it has been necessary to reduce the period of the instruments. During the three months October to December inclusive of the year 1911, 5,092 local shocks were recorded, or an average of 55.34 a day. A finer adjustment of the instruments has since shown that a higher average is recorded.

Mr. Cooke remarks that the results seem to prove that the rocks in the locality are continually breaking, or snapping, a phenomenon which can be accounted for by the rocks being under a great lateral compression and in a state of strain from which, by the underground excavations, they are being gradually relieved.

If I understand him correctly, he supposes that the shocks arise from local relief of pressure afforded by the shafts and slopes. While it is probable that some movement may be thus accounted for, the intensity of the shocks and the description of the movements of the rocks makes it quite beyond question that, as in another passage Mr. Cooke admits, we have here a mine shaft and workings excavated in a zone of faulting.

As remarked by Mr. C. L. Whittle, who called my attention to this interesting case, there seems to be here an unusual opportunity to implace specially devised instruments to record the earth pressure or accumulation of strain: in other words, a seismometer which shall measure the seismic force in the zone of fracture,—for it appears from the account that many of the shocks originate close to the workings. It is to be hoped that the opportunity will be embraced to carry on geological and seismological studies in the Kolar gold field commensurate with the rare opportunity which appears to be here presented.

With two rectangular components of a horizontal pendulum seismograph at a depth of invariable temperature in the mine, it appears possible to detect any tilting movement during the quiescent intervals between shocks by noting the displacement from the zero line if any takes place in a given direction. In fact, here seems to be a seismological laboratory of the first order, deserving a careful and extended

series of observations upon the time of occurrence and intensity of the shocks. Such records for a sufficiently long term of years, correlated with all the suggested causes of earthquakes, not omitting the calculated time of passage of vibrations from distant shocks, should throw important light on the utility or futility of the scientific registration of earthquakes.

EARTHQUAKES AT AREQUIPA, PERU

Mr. Leon Campbell, assistant in charge of the South American station of Harvard College Observatory, has sent the following list of earthquakes recorded at the station during 1912. Some extracts from Mr. Campbell's letter are as follows:

We are situated at the base of the volcano El Misti, which is generally quiet, except that when one is at the summit he can always see jets of steam issuing from its crater. From the Observatory, though, such cannot generally be seen, except at rare intervals. The Chile river divides us from the mountain, so that shocks may be more frequent and stronger in the town of Arequipa, which is on the same side of the river as the mountain. I have recently interested a teacher of the English school in the town to keep a record of the earthquakes felt there, and hope to get more data on this point.

Our instruments are not of the highest order, but they consist of a seismograph, using a smoked plate of glass, and a seismoscope, which when disturbed by an earthquake drops its points and makes an electrical connection with the bells of the grounds. Most of the data given here are of personal observation coupled with the bells ringing. If these data are of any value, you may use them as it suits you. Professor Pickering has given me permission to supply such data to those who care to make use of them.

AREQUIPA STATION, HARVARD COLLEGE OBSERVATORY, AREQUIPA, PERU, S. A.

EARTHQUAKES FELT AND RECORDED DURING 1912.

Date 1912	75th Mer. Time	Intensity R. F. Scale	Remarks
Jan. 6.....	9:52 a.m.....	I	
Jan. 8.....	11:47 a.m.....	I	
Jan. 18.....	11:21 a.m.....	II	
Jan. 18.....	4:04:20 p.m.....	I	
Feb. 11.....	3:09:30 p.m.....	II	
Feb. 12.....	8:34:00 a.m.....	I	
Feb. 20.....	9:01:05 a.m.....	II	
Feb. 27.....	10:47:30 p.m.....	III	Duration 90 seconds. Doors and
Feb. 28.....	1:13:10 p.m.....	II	windows shook.
Mar. 17.....	12:04:00 p.m.....	II	
Mar. 18.....	12:11:50 a.m.....	III	House shook for 15 seconds.
Mar. 22.....	6:12:20 a.m.....	II	
Apr. 3.....	9:57 a.m.....	II	
Apr. 3.....	9:58:15 p.m.....	I	
Apr. 7.....	1:41:45 a.m.....	IV	House suffered a decided jolt, awak- ening observers from sleep.

Apr. 7.....	12:46:00	p.m.....	I	
Apr. 10.....	4:56:20	a.m.....	II	
Apr. 11.....	9:02	a.m.....	III	Windows rattled for a few seconds.
Apr. 12.....	9:01:09	a.m.....	III	House and windows rattled increasingly, lasting for 15 seconds.
Apr. 20.....	9:28:49	a.m.....	I	
Apr. 20.....	10:14:15	p.m.....	II	
May 21.....	5:59:00	a.m.....	III	Windows rattled.
May 21.....	6:46:12	a.m.....	II	
May 22.....	8:09:45	a.m.....	I	
July 5.....	9:58:24	a.m.....	III	Windows rattled for five seconds.
July 7.....	12:27:54	p.m.....	I	
July 26.....	1:59:03	a.m.....	III	Windows rattled.
July 27.....	5:03:55	p.m.....	I	
Aug. 2.....	6:36:00	a.m.....	II	
Aug. 10.....	1:34:04	a.m.....	III	Windows rattled, and again at 1:34:24 a.m.
Aug. 10.....	11:49:34	a.m.....	I	
Sept. 3.....	5:02:34	a.m.....	III	House shook and windows rattled for 10 seconds.
Sept. 4.....	10:11:00	a.m.....	I	
Sept. 7.....	5:35:30	a.m.....	II	Windows rattled for a few seconds.
Sept. 8.....	1:41:15	p.m.....	I	
Sept. 16.....	early	a.m.....	II	Two persons noted slight jar to house and windows, but not certain it was an earthquake until some visitors reported having felt the same in town.
			or III	
Sept. 20.....	10:01	p.m.....	I	
Sept. 21.....	7:28:35	a.m.....	III	Strong enough to rattle house for 15 seconds, and felt by folks at rest.
Oct. 12.....	4:55	a.m.....	I	
			or II	
Oct. 13.....	1:57:15	p.m.....	III	Duration 8 seconds.
Nov. 1.....	7:55:24	p.m.....	III	Windows rattled, and lasted 12 seconds.
Nov. 10.....	7:15	a.m.....	V	Strong shock lasting for about 3 minutes (i. e., the series of shocks), shook the house considerably, rocked beds and alarmed folks generally. Women and children left house. General direction of mark on smoked glass plate NW-SE. Piles of dust on El Misti and pampa to east and south. Steam seen rising from crater of El Misti. Four distinct shocks felt, the third being the strongest. General alarm in town, although no damage done, as far as could be learned.
			or VI	

Nov. 28..... 5:18:40 a.m.....III.....Series of tremors, lasting for 50
or IV seconds.
Dec. 4..... 9:03 p.m..... II
Dec. 6..... 9:02:40 a.m.....III.....Shock felt, lasting 20 seconds.
or IV
Dec. 8..... 5:32:20 a.m.....III.....Felt by several persons.
Dec. 12.....12:18:17 p.m..... I
Dec. 14..... 5:35 p.m..... ?.....If an earthquake, probably a slight
one?
Dec. 22..... 3:45 a.m.....III.....Shock awoke observer.
Dec. 23.....12:52:15 a.m..... V.....Shock very sudden at start, lasting
for 20 seconds, felt by all those
awake.

LEON CAMPBELL.

SEISMOLOGICAL NOTES

In the Azores.—A sharp earthquake shock is reported at Ferreira on the island of S. Miguel. It occurred at one o'clock p.m. on February 6, 1913, and though it caused a considerable panic, there was no damage done.

Teziutlan, Mexico.—At Teziutlan, state of Puebla, Mexico, a light earthquake shock was felt at 12:20 p.m. February 21, 1913. The shock was also felt at the city of Puebla.

In Guatemala.—The newspaper *El Nuevo Tiempo* gives a short account of a violent earthquake in Guatemala on March 8, 1913, at 9:50 a.m. Buildings were thrown down at Cuilapa, and thirty-two school children were killed. Santa Rosa and Barberena also suffered, but not so badly as Cuilapa, which seems to have been near the center of the disturbance.

At Kilauea.—On March 18, 1913, the Kilauea Observatory seismograph recorded an earthquake shock that lasted more than an hour. It is estimated that the focus was 2,500 miles distant.

Earthquake in East Tennessee.—On March 28, 1913, at about 4:50 p.m., a short, sharp earthquake was felt at several places through the valley of east Tennessee. Our colleague, Prof. C. H. Gordon, of the University of Tennessee, is gathering detailed information in regard to it for publication in this *Bulletin*, but lest there should be unavoidable delay in preparing his report the following brief account written by Professor Gordon is given in this place.

On Friday, March 28th, at 4:50 p.m., this city (Knoxville) was visited by an earthquake which was noticeable over an area extending forty or fifty miles with Knoxville as the approximate center.

The shock was of sufficient intensity to cause general alarm, the people rushing into the streets under the impression that there had been an explosion

of the boiler in the basement, or that the building had collapsed. Several clocks were reported stopped by the shock, and in a number of cases bricks were shaken from the chimneys, pictures thrown to the floor, and bookcases toppled over. The shock was felt throughout the city, apparently with an equal intensity. People rushed from their houses and ran hither and thither seeking the source of the explosion. A few who were slumbering at the time were awakened, and those who were sitting were brought to an upright posture. The writer was on the seventh floor of a large building, seated at a table with a number of gentlemen when the shock came. All had the impression that the boiler in the basement had exploded, and rushed to the windows to see if any evidence of the disturbance could be observed. People were seen rushing out of doors and upon adjoining buildings, all looking in very direction to learn if possible the cause of the shock. Those who were out of doors agree that the earth seemed to rise and fall, the shocking ending with a trembling motion. Some say that the movement of the ground was followed by a loud noise which seemed to come as a sharp but muffled rumbling.

One man reports that two feet of the chimney of his house toppled off, and his horse in the stable was knocked down. In a number of homes pictures fell from the walls, and a stovepipe in one residence fell, giving several ladies, the guests of the owner, a severe fright.

The intensity of the shock I estimate to be about VII on the Rossi-Forel scale. As yet, we are without exact information as to the area covered by the shock, but it seems to have covered an area of about forty or fifty miles square in the immediate vicinity of Knoxville. No serious damage has been reported.

A Record at Washington.—On March 30, 1913, the seismograph at Georgetown University recorded an earthquake whose focus is calculated to be between 6,000 and 7,000 miles away. The principal tremor was at 11:25 p.m., but the shock lasted for an hour.

A Shock at Salt Lake City.—April 12, 1913, at 1:30 a.m., an earthquake was felt at Salt Lake City. It lasted for a few seconds only and seems to have had an intensity of about IV R-F scale.

At San Bernardino, California.—A short but sharp earthquake was felt at San Bernardino, California, at 2:45 a.m. on April 13, 1913. No damage was done.

Another Shock in East Tennessee.—An earthquake shock of moderate intensity again disturbed lower east Tennessee and adjacent

portions of North Carolina and Georgia, on April 17, 1913, at 11:30 a.m. The Knoxville papers give reports of the shock from Athens, Madisonville, Etowah, Vonore, Tellico Plains, and Copper Hill in Tennessee, and from Blue Ridge, Georgia. The shock apparently reached its greatest intensity in the vicinity of Madisonville, where a few dishes were shaken from their shelves, and where farmers felt their plows shaken in their hands. No damage is reported. A noticeable feature of the reports is that each one, without exception, mentions a roaring or rumbling sound accompanying the shock. The shock was not felt in Knoxville.

In New York and Canada.—The newspapers report a sharp earthquake through the northern part of the state of New York and in southern Canada on April 28, 1913, at 7:30 p.m. No damage is reported, but it is stated that it was the heaviest shock ever experienced at Ogdensburg, N. Y.

The Aftershocks at Messina.—The following is quoted from *Nature* of March 27, 1913, p. 93:

In common with all other great earthquakes, the Messina earthquake of December 28, 1908, was followed by a large number of after-shocks. A record of the shocks felt at Messina was kept by Mr. G. Spadaro, then a student in the Nautical Institute in that city. During the last four days of 1908, 87 shocks were felt, and during the following year 862. The majority of these shocks were, as usual, very slight, but four, in December, 1908 and January, 1909, were ruinous, and one, in July, 1909, almost disastrous. Dr. Agamennone points out in the *Revista di Astronomia*, etc., for November, 1912, that the distribution of these shocks in time does not follow the simple law which, according to Professor Omori, governs the decline in frequency of Japanese after-shocks, namely $y = k/(x + h)$, in which y is the number of shocks in a given interval at time x , and h and k are constants; for the monthly number is greatest in March, 1909, and shows an increase in frequency towards the end of that year.

REVIEWS

VOLCANOES AND CLIMATE.¹

This is a recent publication by the Smithsonian Institution, giving the views of Messrs. Abbot and Fowle concerning the presence of volcanic dust and haze and their effect in decreasing the transparency of the atmosphere. The ultimate outcome of the work is to determine whether such dust affects terrestrial temperatures, especially those of high stations. Particular reference is made to the haziness of July, August and September of 1912, due to the eruption of Mount Katmai. It appears that the haze produced by the volcano began to affect the measurements of the intensity of the radiation of the sun made with pyrheliometer and spectrobolometer in Algeria about June 19th, and Mount Wilson about June 21st. The eruption occurred June 6th and 7th. The total direct radiation of the sun was reduced by nearly twenty per cent. at the time of maximum effect in August. In the ultraviolet and visible spectrum the effect was almost uniform for all wave lengths, but was somewhat less in the infra-red. From experiments made at Bassour, in Algeria, including measurements by two methods of the radiation of the sky, it appears that the quantity of heat available to warm the earth was diminished about ten per cent. by the haze. The authors note, however, that there was some indication of a decrease in the earth's radiation to space caused by the haze. The following paragraph is of special significance:

Similar periods of haze followed great volcanic eruptions in former years. The influence of Krakatoa, Bandai-San, Mayon, Santa Maria, and Colima seem to have been recorded by measurements of solar radiation, and caused pronounced decrease in the direct solar beam from 1883 to 1885, 1888 to 1894, and 1902 to 1904.

Evidence is presented that the dust layer of 1912 affected terrestrial temperatures, especially of high stations.

A remarkable correspondence is found between the average departures of the mean maximum temperature for fifteen stations of the United States and a curve representing a combination of the sunspot numbers of Wolfer and the departures from mean values of the annual march of direct solar radiation from 1883 to 1909.

A. MCADIE.

¹*Smithsonian Miscellaneous Collections*, 60, No. 29.

ÜBER EINE DYNAMISCHE SKALA ZUR SCHÄTZUNG VON MAKRO-SEISMISCHEN BEWEGUNGEN, by Fürst B. Galitzin (Golycin). 25 pp. St. Petersburg, 1911.

The method of measuring seismic intensity presented by Prince Galitzin in this paper seems to the reviewer to be peculiarly valuable for earthquake study in the California region, as in all districts subject to strong shocks.

Here is described an improvement in the construction and manner of installation of a series of parallelepipeds all having the same basal cross-section, but of different vertical heights; also a thorough treatment of the dynamical theory of the motion when such a series of prisms is shaken by harmonic oscillations of the basement platform. A laboratory method of testing the theory is described; and the results, calculated from theory and observed in the work of testing, are compared, with excellent agreement. Whence is deduced a "rational, dynamic scale" for measuring intensity, depending upon the maximum horizontal accelerations necessary to overturn in succession a series of prisms of graduated stability.

This study seems to the reviewer so important as to warrant the following freely-translated abstract:

. . . It would be better to express the intensity of a shock *directly* by the magnitude of the corresponding earth acceleration, if it were possible to determine this by aid of a very simple and easily available instrument.

A number of such instruments, installed in various places in a shaken district, would afford us a tolerably complete picture of the distribution of the isoseists.

The construction of such a simple instrument can be based upon the phenomenon of the over-toppling of objects of determined form and dimensions.

This idea is not at all new, and attempts in this direction have been made in Japan; this method, however, has not been generally employed, although it is entirely possible upon this basis to develop a purely dynamical and rational intensity scale.

The following constitutes a small contribution to the solution of this important problem.

Let us think of a wooden parallelepiped of height H and of breadth $2c$, (see Fig. 1). In the third direction, perpendicular to the plane of the drawing, this may have any suitable dimension so that it may possess sufficient stability in this direction.

. . . In order to render the overturning edges (axes) A and B more precise, two thin metal strips, obliquely ground and projecting downwards, may be screwed on at the bottom on both sides of the parallelepiped and then placed

between two other metal plates which also are ground obliquely to an edge and screwed to the foundation plate, as is shown clearly in Fig. 2.

By this means a gliding of the body is prevented, but it remains quite free to move (by over-toppling).

(Then follows the dynamical theory and description of experimentation.)

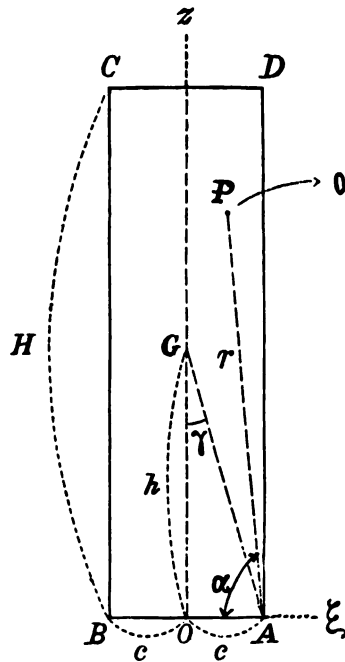


Fig. 1.

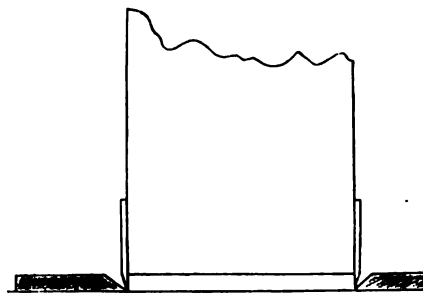


Fig. 2.

... Taking all (the foregoing) into consideration, it certainly can be granted that the theoretic formulas may be regarded as accurate.

On these as a basis a purely dynamical scale can be established by making use of parallelepipeds of several heights but with the same base-dimension, $2c$.

... Investigation of the macroseismic phenomena in various earthquake centers brings out that it is not so much its initial velocity but the *maximum acceleration of the earth-particle*, that denotes the intensity of the corresponding earthquake.

... The question now arises, what relation exists between this critical maximum acceleration and the dimensions of the parallelepipeds.

The critical constant for this is the ratio c/h , that is, the ratio of half the distance between the overturning edges (axes) to the height of the center of gravity of the body above the basement platform.

It proves that this ratio, within the admissible errors of observation, is closely proportional to W_m (W_m = maximum acceleration).

... with the following general relation,

$$c/h = 0.0012 W_m \quad . \quad . \quad . \quad (45)$$

It is quite possible that this factor 0.0012 is to some extent dependent upon c/h , but in the first approximation it can be considered a constant.

On the basis of the relation of equation (45) a *rational, dynamic scale* for the evaluation of the intensity of earthquakes, at least that due to the maximum horizontal acceleration, may be established very easily.

It is necessary only to take a system of parallelepipeds whose heights decrease according to some known law.

For example, this scale may consist of ten different parallelepipeds.

As the least acceleration we will take

$$W_m = 20 \text{ cm/sec}^2 = 20,000 \text{ milligals,}$$

and as the greatest

$$W_m = 200 \text{ cm/sec}^2 = 200,000 \text{ milligals.}$$

Following Cancani's definitions of the several grades of intensity in his scale, the first acceleration-value corresponds to Grade VII and the second to Grade X of the twelve grades of that scale.

Let us take the breadth of the parallelepipeds, that is, the distance between the overturning edges, $2c = 2 \text{ cm.}$, and their length (the longer basal diameter) equal to 11 cm., and allow 2 mm. for the oblique metal strips at the bottom which serve as overturning edges; then we may reckon the height H of a parallelepiped corresponding to a given value of W_m by the following formula:

$$H = 2(h - 0.2) = \frac{2c}{0.0012 W_m} - 0.4 \quad (46)$$

or

$$H = \frac{10,000}{6 W_m} - 0.4 \text{ cm.}$$

The heights of the parallelepipeds computed by this formula for varying values of W_m are given in the following table:

No.	W_m	H	No.	W_m	H
1	20 cm/sec ²	82.9 cm.	6	120 cm/sec ²	13.5 cm.
2	40	41.3	7	140	11.5
3	60	27.4	8	160	10.0
4	80	20.4	9	180	8.9
5	100	16.3	10	200	7.9

If one installs such a series of parallelepipeds and observes which of them fall and which remain standing, two limiting values are obtained for the actual prevailing earth-acceleration W_m .

If we utilize two such systems of parallelepipeds (set with overturning edges) at right angles to each other, we may derive a fairly sure conclusion regarding the direction of propagation of the seismic disturbance.

The length (of the longer basal diameters) of the parallelepipeds, $L = 11 \text{ cm.}$, is so chosen that a maximal earth-acceleration $W_m = 200$ in the direction of the length will not overturn any of the parallelepipeds except the first.

In fact, in order that a parallelepiped with $2c = L = 11$ cm. may overturn, H according to the formula (46) must be

$$H = \frac{2L/2}{0.0012 \times 200} - 0.4 = 45.4 \text{ cm.}$$

H in all cases except the first is smaller than 45.4 cm.

For the first parallelepiped a double length, $L = 22$ cm., may be chosen.

The dynamical intensity scale here described assumes that the true earth motion, for a short time interval, corresponds to a regular harmonic law. The actual relation, of course, is somewhat more complicated in the case of earthquakes. Nevertheless it is advantageous to employ this dynamical method for evaluating the seismic intensity.

. . . Care must be taken in installing such parallelepipeds that their base-platform is strictly horizontal and rigidly connected with the earth.

H. O. WOOD.

IL DISASTROSO TERREMOTO NEL BACINO OCCIDENTAL DEL MAR DI MARMARA, by G. Agamennone.

On August 9, 1912, a severe earthquake affected the regions surrounding the Dardanelles and the sea of Marmora. Great damage was caused by the earthquake and by the fires which followed. In Turkey it was the most destructive earthquake which has occurred within historic times. Few authentic details are accessible. The author gives the following, referring to the city of Dardinelli, given by an eye-witness and published in *La Reforma* at Smyrna, August 13, 1912. The shock occurred about 3:30 and lasted some thirty seconds. Stone buildings fell and the streets were blocked up. Of certain buildings on the shore of the sea the side nearest the sea was damaged, while the opposite side was intact. In other cases the outside walls of houses remained standing while the inner walls were completely wrecked. Along the road from the Austrian to the English consulates the earth opened here and there and hot water gushed out for some time. Ships in the harbor were badly shaken.

Using various details published in *La Reforma* and in *La Tribuna* Professor Agamennone concludes that the territory along both sides of the Straits of Dardanelles and also the inhabited centers surrounding the sea of Marmora were affected, thus comprising a zone of about 300 kilometers long and 200 kilometers wide, in the form of an ellipse, of an area of about 50,000 square kilometers. The center of disturbance seems to have been near the northwest coast of the

sea of Marmora rather than in the Dardanelles, much greater damage having been done near the former point. In the region which suffered most the intensity of the shock seems to have oscillated between IX and X of the Mercalli scale. The territory affected was greater than in the earthquake of Andalusia, December 25, 1884; of Ligionis, February 23, 1887; of Calabria and Sicily, December 28, 1908; and the number of victims was greater than in any of these except the last.

Slight shocks were registered at various remote points in Europe. Comparing the times of these shocks it is shown that the velocity of propagation of the seismic waves was approximately 8.9 kilometers for the primary preliminary disturbance; the velocity of the waves of the secondary preliminary disturbance of lower velocity has not been easy to determine.

C. G. ALLEN.

IL SERVIZIO SISMICO IN GRECIA, NEI BALCANI E NELL' IMPERO OTTOMANO, by G. Agamennone.

This is a note on the development of these studies in the regions named. The various Christian Balkan states are all studying seismology. In January, 1896, the Royal Observatory at Athens began to publish a monthly Seismic Bulletin.

Bulgaria, Austria-Hungary (in Dalmatia, Bosnia and Herzegovina), Servia and Roumania are all studying the subject scientifically. Turkey is the only country which is inactive along this line.

C. G. ALLEN.

IL TERREMOTO DEL 24 GENNAIO, 1912, NELLE ISOLE JONIE E SUA VELOCITA DI PROPAGAZIONE, by G. Agamennone.

This paper discusses the velocity of waves of the earthquake of January 24, 1912, in the Ionian Islands.

The center of disturbance seems to have been between the islands of Zante and Cefalonia, about five kilometers southeast of the latter. Taking the time of day at which the disturbance was felt at twenty-nine other places, Professor Agamennone computes the time at which the shock occurred at the center of disturbance as 16 hours 23 minutes.

•



12 seconds, or 4 hours, 23 minutes, 12 seconds p.m. He also computes the velocity of the waves as 7.68 kilometers a second.

He next computes the time at which the shock should have been felt at the various places provided that this velocity is correct. In many cases this theoretical time coincides with the recorded time, and the difference in the theoretical and the recorded time is never more than a few seconds. This difference may be due to inaccurate recorded time, to instrumental errors, or to a miscalculation as to the center of disturbance.

C. G. ALLEN.

PUBLICATIONS RECEIVED

Comte de Montessus de Ballore.—Fenomeni luminosi speciali che avrebbero accompagnato il terremoto di Valparaiso del 16 di Agosto, 1906. *Bollettino della Societta Sismologica Italiana*, 16, 1912. Modena, 1912.

Fernando de Montessus de Ballore.—Historia Sismica de los Andes Meridionales. Tercera parte. Santiago, 1912.

Dr. E. Tams.—Die seismischen Registrierungen in Hamburg vom 1. Januar 1910 bis zum 31. Dezember 1911. Aus dem *Jahrbuch der Hamburgischen Wissenschaftlichen Anstalten*, 29, 1911. Hamburg, 1912.

H. Gauthier, S. J.—Résumé du catalogue des tremblements de terre signalés en Chine depuis 1767 avant J.-C. jusqu'en 1896 après J.-C. Extrait du *Bulletin de l'Observatoire de Zi-ka-wei*, 33. Chang-Hai 1907. Fasc. C.

Bulletin des Observations. Observatoire magnétique météorologique et sismologique de Zi-ka-wei (Chine) 33, année 1907. Fascicule C, Sismologie, Chang-Hai, 1912.

Jerome S. Ricard, S. J.—Latest advances in weather forecasting at a long range. *Popular Astronomy*, 21, March, 1913.

Estación Sismológica de Cartuja (Granada). Resumen del año 1912.

Boletín Mensual de la Estación Sismológica de Cartuja (Granada) No. 1, Enero 1913.

Observatorio Nacional do Rio de Janeiro, *Boletim Sismologico*, No. 1, 1911. Por A. Lemos.

Bulletin Sismique de l'Observatoire St. Martial, Port-au-Prince, Mai-Décembre 1912.

Bulletin Sismique de l'Observatoire de Zi-ka-wei, près Chang-Hai, Chine. Nos. 19, 20, 21, 22. 1912.

Jesuit Seismological Service. Record of the Seismographic, Astronomical and Meteorological Observatory, University of Santa Clara, California. Nos. 107 to 112 inclusive, 1912-1913.

Mitteilungen der Hauptstation für Erdbebenforschung am Physikalischen Staatslaboratorium, Nos. 1, 2, 3. Hamburg, 1913.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF
THE SEISMOLOGICAL SOCIETY OF AMERICA,
APRIL 10, 1913.

The meeting was called to order by Vice-President Lawson at 2:30 p.m., in Room 104, Bacon Hall, University of California, Berkeley. Directors Burckhalter, Lawson, Louderback, McAdie and Townley were present.

The minutes of the meeting of the Board held on February 4th were read and approved.

The report of the Board of Election was read and accepted, and the following named persons were declared elected Directors of the Society for the ensuing year.

L. A. BAUER,	A. G. MCADIE,
J. C. BRANNER,	C. F. MARVIN,
C. BURCKHALTER,	H. F. REID,
T. A. JAGGAR,	S. D. TOWNLEY,
A. C. LAWSON,	OTTO VON GELDERN,
G. D. LOUDERBACK,	J. B. WOODWORTH.

(The committee's report is attached to these minutes.)

The election of officers for the ensuing year was the next order of business. The following officers were duly nominated and elected:

H. F. REID		President
A. C. LAWSON		First Vice-President
A. G. MCADIE		Second Vice-President
J. B. WOODWORTH		Third Vice-President
S. D. TOWNLEY		Secretary-Treasurer

Ten new members, whose names are subjoined hereto, were recommended by Dr. Branner and the Secretary and duly elected to membership in the Society. Two institutions were placed upon the list of subscribers to the BULLETIN.

The report of the Secretary-Treasurer, printed on another page, was read and accepted.

The salary of the Secretary-Treasurer was continued for another year at the rate of \$20.00 per month.

S. D. TOWNLEY, *Secretary*.

REPORT OF THE BOARD OF ELECTION

The annual election of directors of the Seismological Society of America was held in Room 1404, Merchants Exchange Building, San Francisco, Cal., on April 5, 1913.

The report of the Board of Election is as follows:

PRESIDENT AND MEMBERS SEISMOLOGICAL SOCIETY,

GENTLEMEN:—We, the undersigned judges of election, certify that 145 ballots were cast at the annual election, with the following result:

F. D. Adams.....	68	G. D. Louderback.....	105
B. A. Baird.....	28	A. G. McAdie.....	112
L. A. Bauer.....	83	C. F. Marvin.....	98
G. Blanding.....	25	F. E. Mathes.....	38
J. C. Branner.....	133	F. L. Odenbach.....	31
C. Burckhalter.....	77	H. F. Reid.....	119
C. S. Cushing.....	42	J. S. Ricard.....	38
C. Derleth, Jr.....	65	S. D. Townley.....	110
W. H. Hobbs.....	68	O. von Geldern.....	73
T. A. Jaggar, Jr.....	73	J. B. Woodworth.....	107
A. C. Lawson.....	127		

The following named gentlemen were elected: Branner, Lawson, Reid, McAdie, Townley, Woodworth, Louderback, Marvin, Bauer, Burckhalter, Jaggar, von Geldern.

H. W. TURNER,
WM. G. REED,
A. G. McADIE.

April 5, 1913.

REPORT OF SECRETARY-TREASURER

From April 6, 1912 to April 5, 1913

During the period of this report the membership of the Society has increased from 422 to 426. Two members have been lost through death: Mr. H. E. Kramm of Ithaca, N. Y., and Dr. W. D. Alexander, of Honolulu.

Volume 2 of the BULLETIN of the Society was issued during 1912. This volume contains 283 pages and 15 plates, as against 206 pages and 3 plates in Volume 1.

The financial report is as follows:

GENERAL FUND

Dr.

To Balance April 6, 1912.....	\$ 253.53
Dues and subscriptions.....	731.37
Reprints	27.40
Sale of publications.....	24.00
Transfer from Sayles Fund, interest.....	185.70
Transfer from Sayles Fund, principal.....	200.00
Transfer from Life Membership Fund, interest.....	58.85
Total	<u>\$1,480.85</u>

Cr.

By Stanford University Press, printing Bulletins.....	\$ 974.10
Stanford University Press, miscellaneous printing.....	57.50
Commercial Art Co., illustrations.....	47.64
Barnes-Crosby Co., illustrations.....	8.70
Second-class postage	10.69
Foreign postage on Bulletins	14.02
Miscellaneous postage.....	16.89
Stamped envelopes.....	63.72
Dues, Pacific Association of Scientific Societies.....	5.00
Rent of safety deposit box.....	2.00
Drawing map.....	10.00
Salary of Secretary-Treasurer.....	236.00
Stenographer	8.60
Miscellaneous	9.25
Balance, April 5, 1913.....	16.74
Total	<u>\$1,480.85</u>

LIFE MEMBERSHIP FUND

Dr.

To Balance, April 6, 1912.....	\$ 343.75
Two life memberships.....	50.00
Interest	15.10
Total	\$ 408.85

Cr.

By interest, transferred to General Fund.....	\$ 58.85
Balance, April 5, 1913.....	350.00
Total	\$ 408.85

SAYLES FUND

Dr.

To Balance, April 6, 1912.....	\$5,000.00
Interest from Mutual Building and Loan Association of San Jose and College Park.....	53.50
Interest from Palo Alto Mutual Building and Loan Association....	37.20
Interest from Truckee Lumber Co.....	60.00
Interest from Bank of Palo Alto, Savings Department.....	35.00
Total	\$5,185.70

Cr.

By transfer to General Fund, interest.....	\$ 185.70
Transfer to General Fund, from Bank of Palo Alto.....	200.00
Balance, April 5, 1913.....	4,800.00
Total	\$5,185.70

S. D. TOWNLEY, *Secretary-Treasurer.*

April 5, 1913.

MINUTES OF THE MEETING OF THE SEISMOLOGICAL SOCIETY
OF AMERICA

April 10, 1913

The meeting was called to order by Vice-President Lawson at 3 p.m. in Room 104 Bacon Hall, University of California, Berkeley.

The minutes of the meeting held on April 6, 1912, were read and approved.

Two papers were read before the meeting, the one by Mr. E. F. Davis on "The Marvin Strong-Motion Seismograph," the other by Mr. F. Napier Denison on "The Horizontal Pendulum in Relation to Certain Phenomena." The latter paper was read by Professor Lawson, Mr. Denison being unable to be present.

The meeting adjourned at 4:20.

S. D. TOWNLEY, *Secretary*.

LIST OF MEMBERS ELECTED APRIL 10, 1913

F. C. Brown: Iowa City, Ia.
Anselmo Ferraz de Carvalho: Coimbra, Portugal.
Adam R. Gordon: San Juancito, Honduras, C. A.
C. E. Jamison: Cheyenne, Wyo.
John W. Maller: New York, N. Y.
Euzebio Paulo de Oliveira: Rio de Janeiro, Brazil.
L. F. Pearce: San Juancito, Honduras, C. A.
Anton D. Udden: Rock Island, Ill.

NEW SUBSCRIBERS

The American Geographical Society: New York, N. Y.
Los Angeles Public Library: Los Angeles, Cal.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

- I. Microseismic shock:** recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
- II. Extremely feeble shock:** recorded by several seismographs of different kinds; felt by a small number of persons at rest.
- III. Very feeble shock:** felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- IV. Feeble shock:** felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.
- V. Shock of moderate intensity:** felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.
- VI. Fairly strong shock:** general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.
- VII. Strong shock:** overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- VIII. Very strong shock:** fall of chimneys, cracks in walls of buildings.
- IX. Extremely strong shock:** partial or total destruction of some buildings.
- X. Shock of extreme intensity:** great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

The Bulletin of the Seismological Society of America

VOL. III

SEPTEMBER, 1913

NO. 3

THE HORIZONTAL PENDULUM IN RELATION TO CERTAIN PHENOMENA.¹

By F. NAPIER DENISON.

The object of this paper is to present in as graphic a manner as possible the latest results of certain studies the writer has for some years been carrying on in connection with the Milne type of horizontal pendulum.

In the autumn of 1898 a Milne pendulum was installed at Victoria, B. C., and is one of many throughout the world whose records have continuously furnished valuable data for the B. A. A. S. seismological committee and other institutions.

The instrument is set in the meridian, and points to the south. Apart from the shorter vibrations, such as quakes, tremors, etc., so graphically shown upon the photograph traces, the writer became deeply interested in observing certain wanderings of the pendulum; some lasting for days in the same direction, and sufficient to necessitate adjusting the leveling screw, in order to keep the free end of the pendulum near the center of the photographic paper.

Thinking these movements might be caused by differences of atmospheric pressure over this continent, the writer began keeping a continuous record of these changes from January, 1899, by measuring the exact position of the boom each day at noon, and allowing for leveling adjustments necessary from time to time.

When these readings for the years 1899 and 1900 were studied with the weather charts of the Pacific Slope for the same period, it was found there was a general tendency for the pendulum to swing towards the region of highest barometric pressure, and that the seasonal movement was towards the east during the early summer, and to the west in winter. A secular westerly swing was also very noticeable.

These observations formed the material for a paper read in 1901

¹ Read at the annual meeting of the Society, April 10, 1913.

before the Royal Meteorological Society, and in the autumn of that year further data upon the same subject were personally presented at the Glasgow meeting of the B. A. A. S.

Acting upon the advice of the late Sir George Darwin I have continued the E-W pendulum observations, and have set in operation another instrument set to swing N-S. The latter instrument was personally constructed in 1907, and is mounted in the basement of the General Post-office upon solid rock and at a distance of 500 feet from the E-W pendulum.

Daily curves for both pendulums for the year 1907 were plotted, and when studied with the Coast Weather Chart showed that both pendulums had a general tendency to move in the direction of highest barometric pressure, as well as showing the seasonal and annual change. A resultant direction of northwest and southeast was noticeable.

In 1910 the results of daily readings of the E-W pendulum for the past eleven years were tabulated in various ways, and forwarded to the late Sir George Darwin, who kindly criticised the same, and advised the publication of certain data and the withholding of other material for further study.

In 1911 the writer was permitted the honor of personally presenting before the Manchester Meeting of the International Seismological Association his pendulum results in connection with certain phenomena extending from 1899 to the close of 1911. The same were also presented at the Portsmouth Meeting of the B. A. A. S. by Professor Milne.

Owing to the favorable reception of these papers, the Dominion Government has decided to erect a special Seismological and Meteorological Observatory at Victoria, in order to develop the work already accomplished here.

I now have the pleasure of laying before you these pendulum results extending over a period of fourteen years, from January, 1899, to December, 1912, inclusive, and certain other data in connection with the same.

Treating first the annual or secular movement of the E-W pendulum, we find in Fig. 1, curve *B*, which represents the mean annual position of the pendulum during the above period, that a maximum westerly movement is reached in 1900, then an almost steady easterly swing sets in until 1906, followed by a westerly movement to 1908, then a still

greater easterly swing to 1910 and 1911, followed in 1912 by another marked westerly deflection. The annual mean value for this period is 259.5 millimeters. This is termed the "Normal," and is shown in Fig. 1 by the dotted line.

Having suspected for some years that this annual curve may be due to other than local disturbances—such as changes of temperature and air pressure, ocean tidal loading, etc.—curve *A* in Fig. 1, representing the annual number of earthquakes recorded here, was plotted

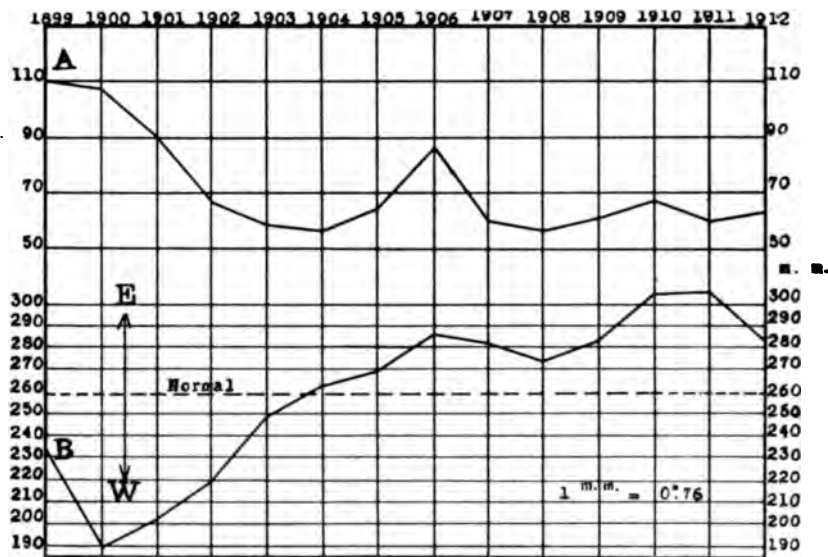


Fig. 1.—*A*. Number of earthquakes recorded at Victoria, B. C.

B. Mean annual position of E-W horizontal pendulum at Victoria, B. C.

above the pendulum curve. We at once find that during the years when the pendulum is farthest from the normal line the greatest number of quakes were recorded here, and the fewest when the pendulum curve is nearest to the normal.

These curves suggest that the years of maximum earth unrest, viz: 1899, 1900, 1906, and 1910, are also times of abnormal pendulum movements, while 1904, 1908, and 1912 are normal years.

In the endeavor to detect the presence of slow changes in the vertical along the Pacific Slope, I have been furnished, through the courtesy of the Director of the U. S. Geodetic and Coast Survey, the mean sea-level data for certain stations. These are plotted in Fig. 2, and

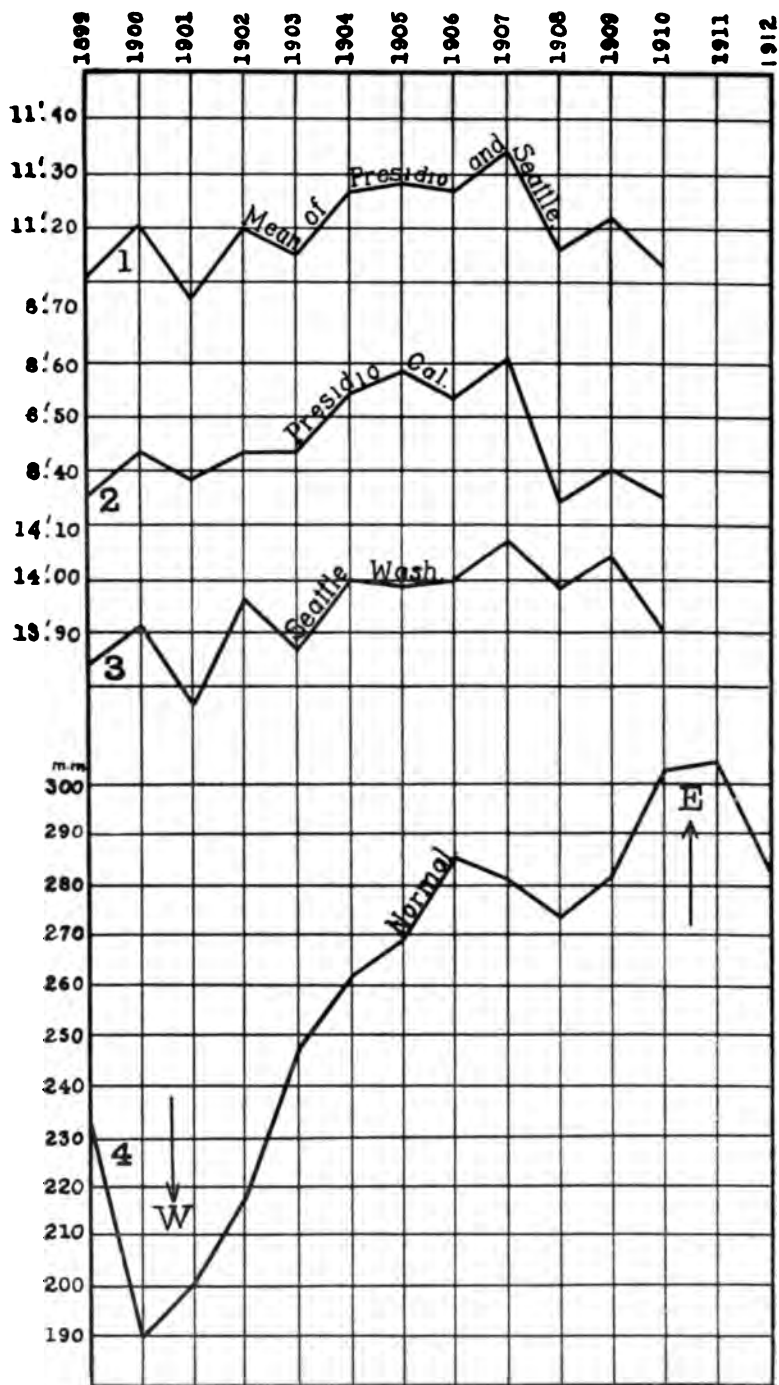


Fig. 2.—1, 2, 3. Mean sea-levels.

4. Mean position of E-W pendulum.

give the annual curves for Seattle, Presidio, and the mean of the two. Below is the E-W pendulum curve. From the former three we find the mean sea-level was lowest on the Pacific Coast in 1901, and highest in 1907, while on the Atlantic Coast the mean sea-levels were reversed. Comparing the Pacific mean sea-level curves with that of the E-W pendulum, we find that a year after the pendulum has reached its maximum westerly swing, the Pacific Coast has reached a maximum elevation; while the apparent maximum coastal depression occurred in 1907, also a year after the 1906 maximum easterly pendulum movement. Owing to lack of 1911 and 1912 sea-level data, I am unable to state whether another apparent maximum coastal depression occurred after the 1910 and 1911 easterly pendulum extreme took place.

This study of coastal changes in seismic countries has received considerable attention, particularly in Italy and Japan. In the *Bulletin of the Imperial Earthquake Investigation Committee*, 5, No. 2, Dr. Omori treats it in a most thorough manner. Plate XXI of his paper gives sea-level changes for Keelung, Formosa, 1899-1911, in which the minimum level occurs in 1902 and the maximum in 1909; and Plate XXV shows a minimum level in 1900 at Pola, Austria, and a maximum in 1908.

Although these sea-level readings are reduced to a barometric standard, it is most difficult to determine to what extent these observations indicate a coastal change of level when dealing with the vast Pacific Ocean, where the prevalence of cyclonic or anti-cyclonic areas in certain latitudes must have a large influence upon sea-level variation. Briefly, then, the sea-level curves in Fig. 2 indicate an abnormally low sea-level in 1901, and unusually high in 1907. Both may be due to a primary cause in 1900 and 1906.

To carry this investigation still further, I have, in Fig. 4, *A*, plotted the mean annual magnetic horizontal force at Toronto, Ont., for the past fourteen years. Polar motion as observed at Ukiah, Cal., (*B*), and again the E-W pendulum curve (*C*). In the magnetic curve, I wish to draw your attention to the fact that whereas the decrease is almost steady from 1901 to 1909, and parallels the dotted line, there is an unusual increase in 1900, and an abnormal decrease in 1910 and 1911. It is interesting to note that the years of greater magnetic increase and decrease correspond to the extreme westerly and easterly swings of the pendulum.

Considerable attention has recently been drawn to an apparent con-

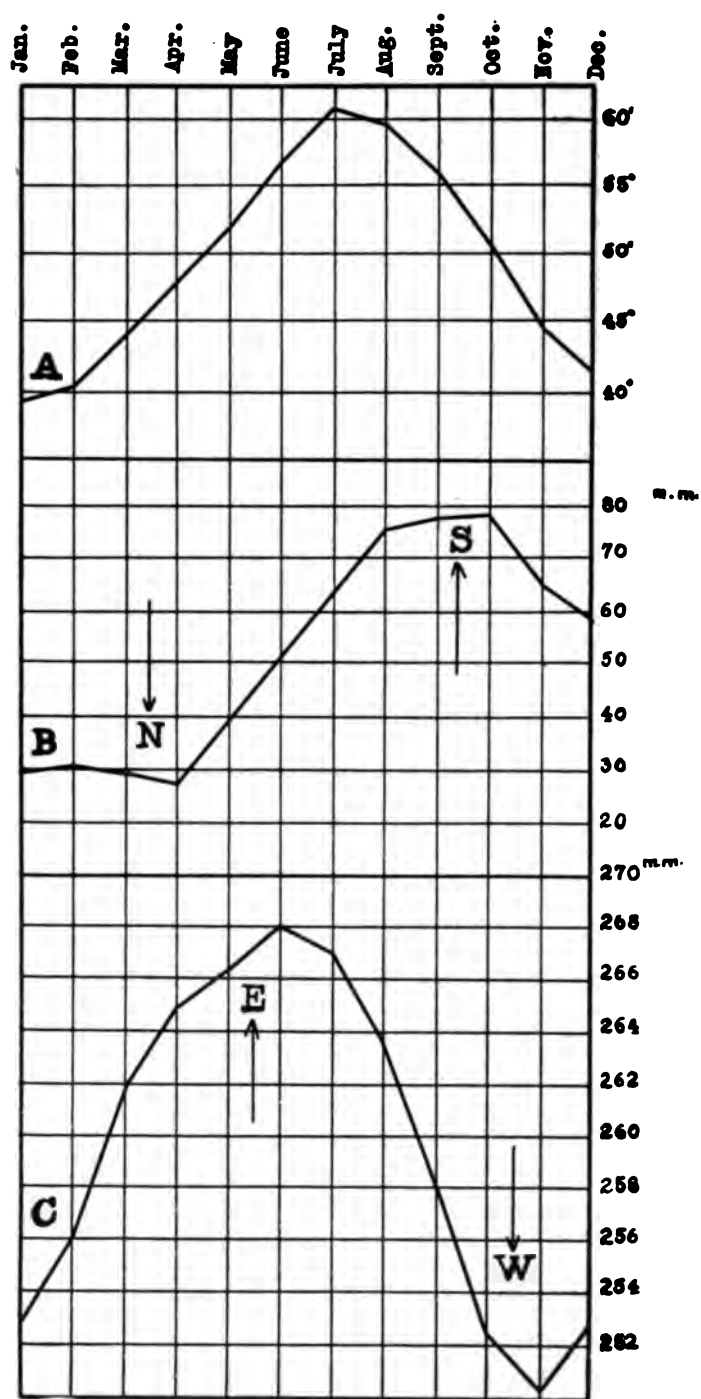


Fig. 3.—A. Mean temperature at Victoria, B. C.
 B. Mean position of N-S pendulum.
 C. Mean position of E-W pendulum.

nection existing between megaseisms and latitude variation. Curve *B*, Fig. 4, gives the polar motion as measured at Ukiah, Cal., and taken from the *Astronomische Nachrichten*. This curve clearly shows that the years of least and greatest polar motion are also the years of maximum earthquake frequency, and when the E-W pendulum is farthest from its normal position.

As it has been suggested that the temperature conditions have a marked effect upon pendulums installed upon the earth's surface, the writer has, in Fig. 3, plotted the mean monthly temperature for Victoria for twenty-four years, the mean monthly position of its N-S pendulum, and the same for the fourteen years E-W pendulum observations. The temperature curve reaches its extreme in July and January, while the E-W pendulum does so in June and November; and the other pendulum reaches its maximum northerly movement in April, and southerly in October. The E-W pendulum, then, reaches its extreme about the time of the summer and winter solstices, and the N-S instrument about the time of the equinoxes.

In order to demonstrate the individual monthly and seasonal movements of the E-W pendulum during the last fourteen years, Fig. 5, curve *A*, has been constructed. Here it may be noted the maximum easterly swing occurs earlier than the mean during the first few years, and the marked secular westerly movement is most prevalent to November, 1900; then the secular swing is to the eastward, crossing the normal in 1904, and continues to 1906, followed by a close approach to the normal in 1908; and after another marked easterly movement to 1910, the curve reaches the normal again in December, 1912.

As the writer has reasons for believing there is some connection between colliery gas explosions and periods of maximum earth unrest, he has shown at *B*, Fig. 5, by dots the number and distribution of 139 colliery gas explosions which have occurred in North America. It will at once be observed that these are in groups, mostly occurring at the times of the summer and winter pendulum extremes. In order to show the annual number of these, the dotted line *C*, Fig. 5, is given.

It is interesting to note that the smallest number of explosions occurred in 1904, when the pendulum curve is at normal and the fewest earthquakes took place.

The number then increases on either side of 1906, falls to another minimum in 1908; so also does the earthquake curve, and the pendulum



Fig. 4.—A. Mean magnetic horizontal force at Toronto, Ont.
 B. Polar motion at Ukiah, Cal.
 C. Mean position of E-W horizontal pendulum, Victoria, B. C..

approaches normal; then in 1909 and 1910 America was shocked by no less than forty gas explosions, while in 1911 and 1912 the number of these dread disasters fell off considerably; so also do we find the pendulum curve approaching normal, and the earthquake curve much reduced.

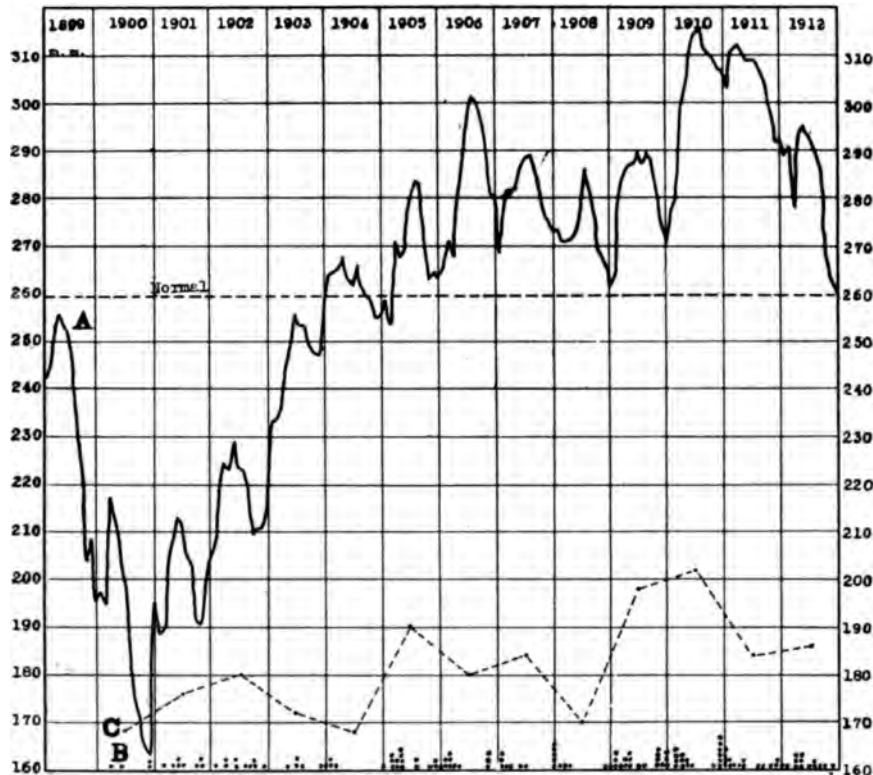


Fig. 5.—*A.* Mean monthly position of E-W horizontal pendulum at Victoria, B. C.
B. Number and distribution of colliery explosions in North America when five or more lives were lost.
C. Annual number of colliery explosions in North America.

This investigation is also being carried on a thousand feet underground in the Western Fuel Company's colliery at Nanaimo, where one of the writer's pendulums is in operation; and from results already obtained the low-level readings, removed from temperature changes, are to a large extent bearing out the pendulum movements recorded on the surface.

The following is a summary based upon the above diagrams and tables relating to this interesting subject:

Although changes of temperature, difference of barometric pressure, ocean tidal loading, precipitation and other forces yet to be studied, may affect the pendulum readings under discussion, the writer is inclined strongly in favor of the theory that a certain proportion of this curve represents the presence of slow earth strains and movements ever active throughout the world, but probably more pronounced at Victoria, which is situated not far distant from the great continental line of weakness and seismic zone extending from Alaska to South America.

The normal seasonal fluctuations may be due to solar influences, while the annual or secular movements appear to be controlled by several mysterious forces of different periodicities, that may not be fully determined until a few more years' results have been obtained.

The further study of these earth strains and slow movements may prove of great practical value in determining the probable times when dangerous seismic conditions might prevail in certain areas, and also aid in determining when extra precautions should be used in collieries to detect abnormal gas escapements during such critical times.

It is also hoped that these pendulum movements, which in some countries are termed "displacements of zero," may help to solve some of the marked cyclic climatic changes known to exist in various portions of the world.

I therefore respectfully urge this Society to assist this line of research by establishing other pendulum record stations of a uniform type throughout the Pacific Slope, in order that, in future, the Victoria results may be linked with others extending from Alaska to at least California, and a continuous daily survey made of all slow movements known to be ever present.

ON THE OCCURRENCE OF EARTHQUAKES IN
SOUTH AFRICA.

By H. E. Wood.

At the end of 1905 the Transvaal Meteorological Department (under the direction of Mr. R. T. A. Innes) undertook, at the request of the "Kaiserliche Hauptstation für Erdbebenforschung," to collect information relating to seismic disturbances over the Transvaal, and with this object sent printed question postcards to many of its meteorological observers in many parts of the Province. These postcards were to be filled up after the occurrence of any seismic disturbance and returned to the Department. Much information was obtained in this way with regard to the seismic conditions of South Africa.

The general impression as regards South Africa is that it is particularly free from any great seismic instability, and this view appears to be confirmed by the records. During the period of seven years covered by these records there has not been a single earthquake of any great importance in South Africa, and only three shocks which have been at all widely felt within that region. These are the earthquakes of August 5, 1909, October 21, 1910, and February 20, 1912. In 1905 Professor Milne stated that for ten years at least Africa had not produced a single world-shaking earthquake, and the statement still holds good. In particular South Africa seems to be more stable than the rest of the continent, as, according to Professor Milne, the greatest seismic activity is to be found in the high lands of Algeria and in the vicinity of the Great Lakes and Abyssinia.

In February, 1908, considerable interest was aroused in seismological questions by the occurrence on the Witwatersrand of a series of local earth tremors. In order to obtain additional information as to the origin of these shocks,—*i. e.*, whether they were truly tectonic or whether they were to be attributed to the extensive gold-mining and water-pumping operations taking place on the Witwatersrand,—seismographs of the Wiechert type were installed at the Transvaal Observatory in 1910. These instruments have successfully recorded the Witwatersrand tremors, the South African earthquakes of October 21, 1910, February 20, 1912, November 17, 1912, and many distant earthquakes.

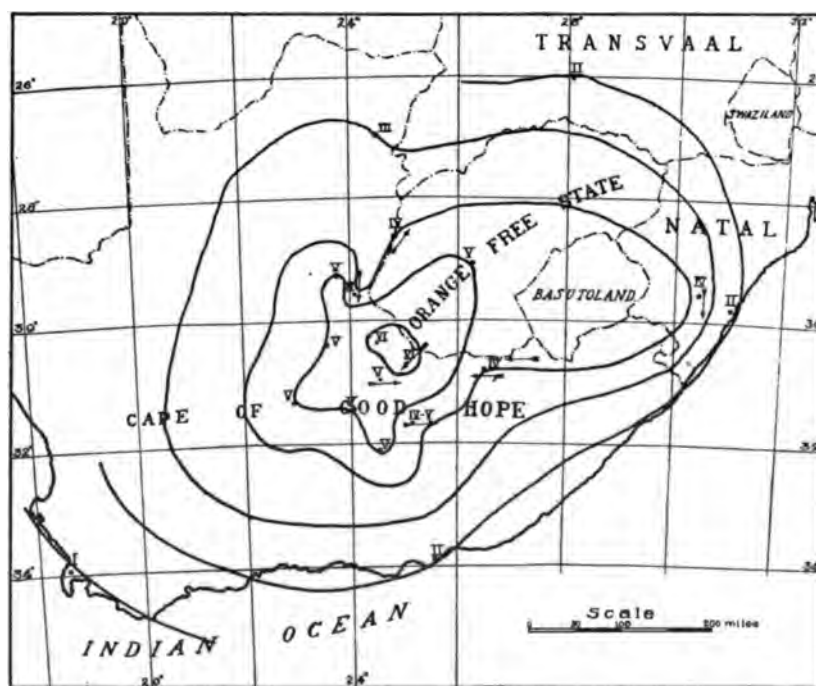
As regards the Witwatersrand earth tremors the evidence of the seismograph records is to the effect that these are essentially local in character, and are not to be classified as true tectonic earth movements. During the five years 1908-1912 there have been reported seventy local shocks of sufficient intensity to be felt by people living on the Witwatersrand. The shocks tend to become much more frequent each year: in 1908 seven were felt, in 1909 three, in 1910 twelve, in 1911 thirteen, and in 1912 thirty-five. Of these seventy shocks fourteen occurred in the first quarter of the year (January-March), seventeen in the second quarter, twenty-one in the third quarter, and eighteen in the last quarter. There is not yet sufficient material to indicate whether their occurrence is influenced in any way by meteorological conditions, *e.g.*, whether they are more frequent in the dry or the rainy seasons.

The effect of these locally felt tremors on the Wiechert seismographs is much less than that of the unfelt distant earthquakes. The record of a local tremor always shows a sudden "kick" of the needles, with no preliminary tremors and very rarely any succeeding tremors. It suggests that there has been a sudden single blow or impact on the earth's crust in the vicinity, and that a solitary wave has traveled outwards from the center of disturbance. It is the sudden transition from the normal state of rest which causes this single disturbance to be noticed so generally, whereas the larger periodic movements associated with distant earthquakes pass unfelt. Local shocks of this nature appear to occur only along the Witwatersrand in South Africa; and this fact naturally leads to the opinion that they are to be attributed to the extensive mining operations carried on there. Whenever excavations are made at any depth in the earth's crust the previously existing forces—rock pressure, etc.—are thrown out of equilibrium. These forces must re-adjust themselves again, slowly or suddenly. If the process is slow the result is a rising of the foot-wall and a slow closing-up of the stopes in the mines; if the process is sudden there is a sudden small movement of enormous masses of rock, and the result is the propagation of a wave across the Witwatersrand which is observed as a "local tremor." A tremor which was felt generally over Johannesburg on August 16, 1910, was definitely associated with a movement in the Ferreira Deep gold mine.

Thus, although slight earth shocks are of very frequent occurrence over the Witwatersrand, this region is not considered as of any seismological importance. The fact that the increase of rock temperature

with depth in the Witwatersrand gold mines is very small compared with the increase in mines in other parts of the world would show that the conditions here are very stable and have been so for a very long period. Mr. H. F. Marriot found that the increase of temperature with depth in the Witwatersrand gold mines was only one degree Fahrenheit for each 208 feet. (254 feet according to Mr. Wother-spoon, taken as an average of forty observations down to 4,000 feet.)

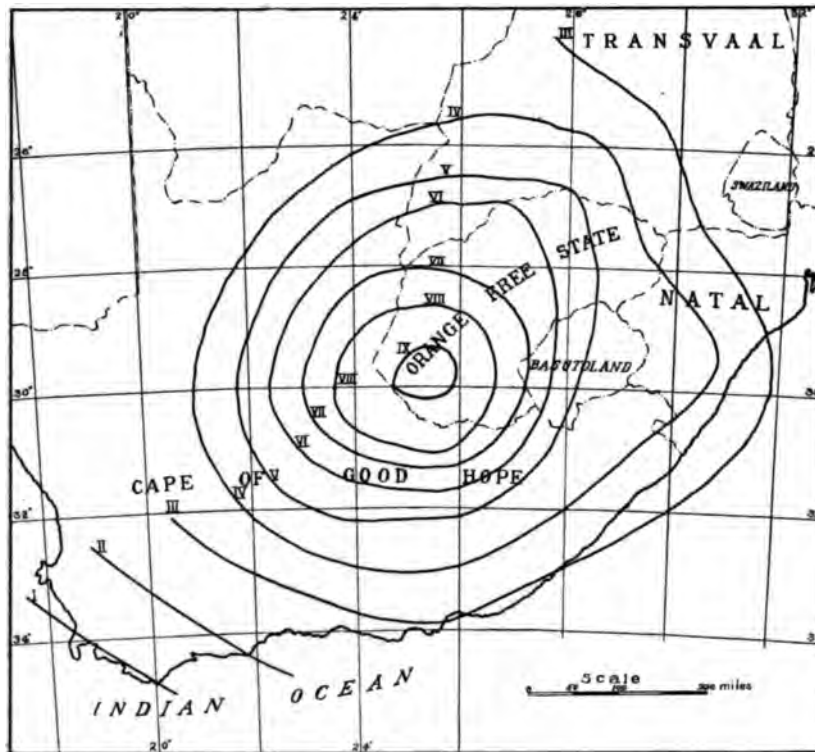
On October 21, 1910, the Wiechert instruments registered a semi-distant earthquake, the distance of the epicenter being deduced from the record as about 350 miles. Many personal observations of this shock were received from places in the Orange Free State, Natal, the Cape Province, and the Transvaal. From the observers' descriptions the intensity of the shock (on the Rossi-Forel scale) was estimated, and from these data Map I, showing the isoseisms of this earthquake, was constructed. This gave the location of the epicenter of the shock as $24^{\circ} 45'$ east longitude, $30^{\circ} 30'$ south latitude. This is at a distance



Map I. Earthquake of October 21, 1910.

from Johannesburg of 350 miles, agreeing with the epicentral distance as determined from the seismograph records.

On February 20, 1912, a much more severe earthquake was recorded by the instruments, the epicentral distance being calculated as about 300 miles. This shock was felt over the whole of the South African Union, and the very numerous reports received enabled the isoseisms of Map II to be drawn with fair accuracy. The epicenter



Map II. Earthquake of February 20, 1912.

of this shock was found to be about $25^{\circ} 06'$ east longitude, $29^{\circ} 45'$ south latitude, at a distance from Johannesburg of about 310 miles. This earthquake did considerable damage in the district south of Koffyfontein, many farm buildings being completely destroyed. As far away from the center of the shock as the town of Kimberley cracks were formed in the walls of buildings. On the Orange Free State-Cape border near Petrusville certain eye-witnesses saw kopjes emitting

what appeared to be clouds of smoke, and a volcanic origin was suggested for this earthquake. It is much more probable, however, that what was seen was a cloud of dust raised by the dislodging of stones and boulders from the sides of the kopjes, which lay not very far from the region of greatest disturbance.

This earthquake was followed by a series of less intense shocks; and there have been others reported from this vicinity, notably on April 19 and November 17, 1912.

This region—the southern part of the Orange Free State along the Cape border—thus appears to be the center of greatest seismic instability in the Union of South Africa at the present time. Other seismic regions of rather less importance lie in the Rustenburg district of the Transvaal, in the Zoutpansberg district of the Transvaal, and over Swazieland and Zululand, Natal.

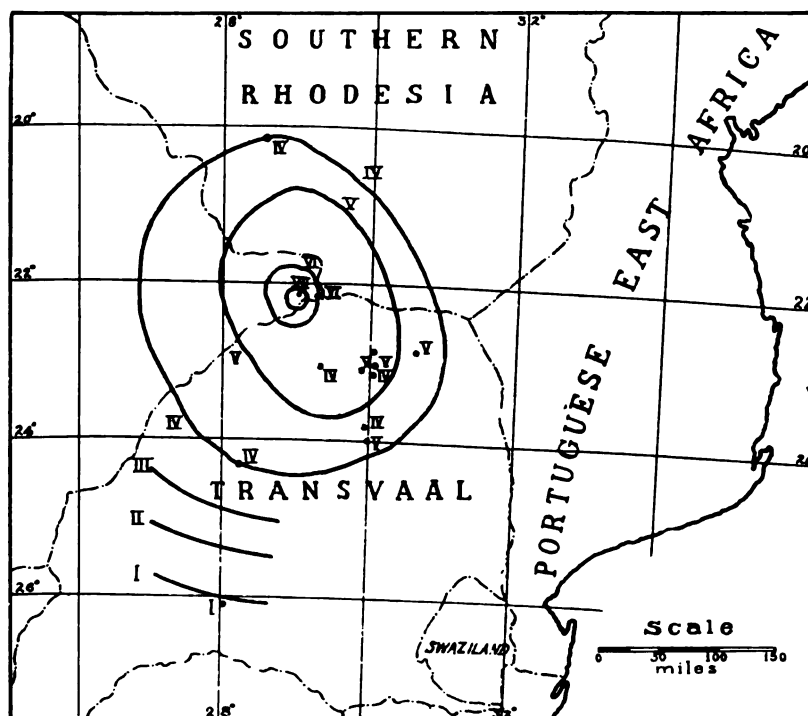
Although no intense shocks have been reported from the Rustenburg district, subterranean rumbling noises of almost daily occurrence have been heard for several years. Numerous slight shocks have been reported from Rooiberg in the northeast of the district, and also from Warmbaths.

On August 5, 1909, there was a rather severe shock in the Northern Zoutpansberg, which was felt as far away as Bulawayo and Johannesburg. The reports of this shock were sufficiently numerous to enable the isoseisms of Map III to be drawn. The Seta diamond mine lay not far from the center of this shock, and Mr. Forbes Mackenzie has supplied me with his interesting personal experiences:—

At 10:45 a.m. to-day we felt a severe earthquake shock. I happened to be down in the mine superintending some work there. My attention was first caught by a muffled rumbling sound, then the earth shook, and I had quite a difficulty in keeping my feet. The natives all stumbled into the center of the mine like a frightened flock of sheep. The ground on the edges of the mine began to tumble in. The rustling-like movement of the ground forming the various sides of the mine shook out clouds of dust. In fact every pebble and every grain of sand seemed for the space of twenty seconds to be out on its own account and to have thrown off its conglomerate fastening. The driver of the hauling engine thought that the boilers had burst, and on looking out he saw every stone of a dry-stone wall dancing about on its bed. The wall is fourteen feet high, ten feet broad at the base and six feet at the top. The whole fabric seemed to bulge out and was on the verge of falling, when it settled back and everything was still. The man at the pumping station was down in the well oiling his pump

when the shock occurred. The timber-lined walls seemed to be falling in on him and the pump was moving about. Hastily he crawled out, shut off steam, and came up to see if the magazine had exploded. The pumping station is three miles away from here on the Limpopo.

No earth shock of any importance has been reported from Swaziland and Zululand, but the frequency of minor shocks in these regions seems to imply a center of seismic activity in the vicinity.



Map III. Earthquake of August 5, 1909.

The general conclusions from the study of these records confirms the general opinion that South Africa is on the whole extremely stable from a seismological point of view. There are, however, within it four distinct regions of instability remaining, the most important of which lies in the south of the Orange Free State. It is perhaps worthy of note that this region lies near and includes part of the chief diamond-bearing region of South Africa, and that diamonds also occur in the

SOUTH AFRICAN EARTHQUAKES

DATE	LOCALITY	TIME H. M.	Direction	Intensity	REMARKS
1906					
May 5	Warmbaths, Tvl.	17 20	N to S		Duration 10 seconds.
May 20	Warmbaths, Tvl.	12 30	N to S	IV	Duration 20 seconds.
June 2	Warmbaths, Tvl.	21 45			Two slight shocks.
Aug. 27	Amsterdam, Tvl.	11 00	S to N	V	
Dec. 10	Swazieland	10 12			Felt also over Ermelo, Piet Retief and Wakkerstroom districts and in Natal.
1907					
Mar. 3	Leydsdorp, Tvl.	4 00	S to N	VI	Two tremors. Natives remember a previous shock in 1904.
June 6	Warmbaths, Tvl.	9 00			Two very slight tremors.
June 15	Warmbaths, Tvl.	2 00			
June 22	Kasempa, Rhodesia	3 01		VI	
Aug. 5	Mbabane, Tvl.	6 50	W to E		Also felt at Lake Chrissie and Oshoek.
Sept. 6	Rhodes Drift, Tvl.	21 30		IV	
1908					
Feb. 20	Tzaneen, Tvl.	4 45		V	
June 13	Vryheid, Natal	20 30			Several distinct shocks.
June 25	Rooiberg, Tvl.	10 35		IV	
Aug. 18	Bloemfontein, O. F. S.	5 00	S to N	V	
Sept. 15	Rooiberg, Tvl.	9 10			
Sept. 24	Zoutpansberg, Tvl.	20 50			Felt over the Zoutpansberg district.
Sept. 26	Bloemfontein, O. F. S.	23 07		V	Felt over the O. F. S. and the S. W. Transvaal.
Sept. 29	Carolina, Tvl.				Shocks felt at Carolina and along the Swazi border.
Nov. 5	Carolina, Tvl.	20 00			Felt also at Lake Chrissie.
Dec. 25	Pretoria, Tvl.	16 08			Felt near Pretoria and at Robinson and Krugersdorp.
Dec. 30	Krugersdorp, Tvl.	2 15			This shock was also felt at Springfontein Garries, Vanrhynsdorp and Port Nolloth in Cape Colony.
1909					
April 15	Alfred County, Natal			IV	Early morning.
May 7	Rooiberg, Tvl.	10 17			Duration 8 seconds.
May 8	Rooiberg, Tvl.	10 22			Duration 6 seconds.
May 8	Rooiberg, Tvl.	10 40			Duration 10 seconds.
May 14	Rooiberg, Tvl.	10 48			Duration 10 seconds.
Aug. 5	Zoutpansberg, Tvl.	10 37			Special report and map.
Aug. 17	Leydsdorp, Tvl.	14 20		III	Duration 40 seconds.
Oct. 14	Rooiberg, Tvl.	3 45		III	
1910					
May 15	Nomahasha, Swazieland	7 00			
May 19	Warmbaths, Tvl.	20 30			Duration 3 seconds.
May 28	Livingstone, Rhodesia	8 30		VI	
Aug. 16	Schroedershof, Swazld.	0 00	E to W		Duration 15 seconds.
Oct. 21	O. F. S. Earthquake	20 43			Special report and map.
1911					
July 6	Oudtshoorn, C. P.	22 15			
Aug. 6	Hlatikulu, Swazieland	18 30			Duration 8 seconds.
Oct. 24	Rooiberg, Tvl.	5 45			
1912					
Feb. 20	O. F. S. Earthquake	15 04			Special report and map.
Mar. 20	Krugerspost, Tvl.	20 30		V	
Mar. 21	Krugerspost, Tvl.	1 09			Felt in Lydenburg Dis.
Apr. 19	Koffyfontein, O. F. S.	20 00	E to W		Duration 20 seconds.
Nov. 17	Koffyfontein, O. F. S.	1 43			Felt also at Kimberley.

Zoutpansberg region. The subterranean rumblings in the Rustenburg district may be connected with the existence of large underground water-supplies in rock fissures. The Swazieland and Zululand region lies on the great slope from the Drakensberg chain of mountains to the sea, and the origin of its earth tremors may be sub-oceanic.

Note added by Mr. Schwarz.—Besides the areas described by Mr. Wood, that of the south flank of the Drakensberg may be noted as being frequently shaken by small earthquakes. The mountains consist of lava and are steeply scarped on the south side. Residents say that the shocks always travel from west to east, *i. e.*, towards Natal. The earthquakes in Cape Town are due to local subsidences; it is remarkable that in an area of such strong relief, where the Table Mountain rises abruptly over 3,000 feet from the sea, there should be so few disturbances.—E. H. L. SCHWARZ.

EARTHQUAKE AT WESTPORT, NEW ZEALAND.

By F. G. MORGAN.

The earthquake reported in the *Bulletin of the Seismological Society of America*, 3, 36, is that which occurred at Westport on February 22d. It was not felt at Wellington, which is 166 miles in a straight line northeast of Westport. The writer was in Westport at the time, and offers the following account of the occurrence for publication in the BULLETIN:

A severe earthquake, almost VIII on the Rossi-Forel scale, occurred at Westport, on the west coast of the South Island of New Zealand, at 0 hrs. 38 min. p.m. New Zealand mean time (11 hrs. 30 min. ahead of Greenwich) on Saturday, February 22, 1913. The shock lasted for nearly a minute, and was recorded as felt from Nelson, ninety-two miles to the northeast, to Hokitika, seventy-three miles to the southwest. These were not, however, the extreme limits. Either the same shock, or possibly a companion, was recorded by some of the Australian seismographs. The origin is believed to have been a few miles to the westward or northwestward of Westport, and at a comparatively moderate depth. The earthquake may with fair certainty be ascribed to movement along a northeast to southwest fault-plane or zone, parallel to the general trend of the coast line.

In the town of Westport and vicinity the shock was preceded and accompanied by a loud rumble of varying intensity, resembling the firing of heavy artillery, or a series of quarry blasts. The first vibrations felt were strong; then for a second or two the vibration appeared to decrease, and then regained strength for twenty or thirty seconds, thereafter gradually dying away. Many chimneys were partly, but in no case known to the writer, wholly destroyed; the upper portions collapsed, or were twisted through a small angle, and cracks were, of course, numerous. The brick walls of the new post-office were somewhat badly affected, and part of the building was shifted one-quarter to one-half an inch on its foundations. In the shops and dwellings (all of wood, with iron roofs) numerous articles were thrown off shelves, especially those running north and south. In this

way considerable damage was caused, owing to breakage of bottles, crockeryware, etc. Several plate-glass windows were broken, and many gas mantles, especially those of the inverted type, destroyed. Practically all persons inside buildings made hurried exits. A few were affected by nausea, and several women fainted.

At Cape Foulwind, six miles west of Westport, cracks opened in the ground, and mud issued from one. A small stream was reported as having temporarily dried up. It was also stated that after the earthquake the sea receded at this place.

The day of the earthquake was that of the spring tides, and the time nearly two hours after high water. At Westport the tide was reported as extraordinarily high, the tents of campers near the beach being all but invaded by the sea shortly after the earthquake; whilst at Ngakawan, twenty miles to the northeast, the tide was over three feet above ordinary springs, and perhaps five feet. At Karamea, about fifty miles to the northeast of Westport, the tide was reported as the highest for several years. An earthquake water-wave is thus indicated.

Outside Westport the shock seems to have been felt with approximately the same intensity for about fifteen miles in either direction along the coast line. The land surface near the coast in general consists of little consolidated gravel or sand resting on harder rocks, and therefore would be more strongly affected than the hard rock areas a short distance inland. The coal-mining townships or villages of Denniston and Millerton, a few miles inland, and built on solid rock, felt the earthquake in a notably less degree than Westport. In the coal mines the shock itself was not particularly severe, and no damage was done; but the loud accompanying rumbles naturally gave rise to the belief that an explosion of firedamp had taken place. The only damage done by the earthquake away from the narrow coastal belt consisted in a few small slips on the sides of roads cut along sidlings. On banks of streams and perhaps elsewhere a few trees were uprooted.

At Greymouth, about fifty miles southwest of Westport, and like that town built on a coastal plain with gravel and sand surface, the shock was felt somewhat severely. Chimneys were damaged, many articles were shaken from shelves, the bell of the town clock struck, and many people rushed from their houses into the streets. Several persons were reported as affected by nausea, and one or two members of the weaker sex were said to have fainted. At Karamea, about fifty miles to the northeast of Westport, the shock was also severe.

During the remainder of the day, and for the next two or three weeks, numerous minor shocks took place. Of these no exact record has been kept, but it is said that in all over seventy shocks were felt in the town of Westport.

The writer's record extends from February 22d to March 12th. From March 1st, and during some of the preceding days, the writer was a few miles inland from Westport, and was therefore not in a position to note all the shakes felt in the town. Some thirty-nine after-shocks are indicated in the record. Of these fifteen were distinct shakes accompanied by rumbling; seventeen were noted only as shakes, though in some cases probably attended by rumbles; and in seven cases rumbles only were noted. The writer actually observed twelve shocks with rumbles; eight without rumbles were noted, and the seven rumbles unaccompanied by shakes perceptible to the senses.

WELLINGTON, NEW ZEALAND, July 2, 1913.

EARTHQUAKES IN BUCKINGHAM COUNTY, VIRGINIA.

By STEPHEN TABER.

Earthquakes of low intensity have frequently been felt in the central portions of Virginia, and several of these disturbances are known to have originated in the vicinity of Arvon, in Buckingham county. Most of the earthquakes have had an intensity of V or lower in the Rossi-Forel scale, but at least one has been recorded with a maximum intensity of VII or higher. During the summers of 1910 and 1911, while preparing a report on the gold belt in the James River basin, the writer made a detailed study of the geology in this region.¹ The geologic structure furnishes a probable explanation of the seismic disturbances, and it is the purpose of the present paper to discuss this question and give a brief description of some of the earthquakes.

The district under consideration (see Fig. 1) is situated a little east of the geographic center of the state; and, physiographically, is located in the center of the Piedmont Plateau province. It presents the surface features characteristic of the Piedmont Plateau throughout Virginia: low relief, a network of streams affording perfect drainage, and a deep mantle of residual decay, which covers most of the country except where the larger streams have carved out their valleys. The land is gently rolling, consisting of broad, flat-topped divides and narrow valleys. The ridges are remarkably uniform in elevation, ranging from 450 feet above sea-level in the eastern portion of the area to 550 or 600 feet on the west. The only variation in the monotony of the topography is furnished by Willis Mountain in the southeastern part of Buckingham county, which rises as a solitary monadnock to a height of 1159 feet above sea-level. The larger streams have entrenched meanders and flow in a general easterly direction across the structure of the country, while the smaller streams are for the most part adjusted to the rock structure.

The general distribution of the principal rock formations is shown on the geological map of the area given in Fig. 1. The oldest rocks are pre-Cambrian metamorphic rocks, chiefly sedimentary in origin,

¹Stephen Taber, "Geology of the Gold Belt in the James River Basin, Virginia," *Virginia Geological Survey*, Bulletin No. 7, 1913.

1

2

3

4

5



Fig. 1.—Ordovician sedimentary rocks resting on eroded surface of granite.



Fig. 2.—Normal fault in Ordovician slates.

consisting of schists, gneisses, and quartzites. After their deposition they were subjected to powerful forces acting in a northwest-southeast direction, which resulted in close folding, faulting, and the development of a highly schistose texture. These rocks have a fairly uniform strike in a northeast and southwest direction, and dip toward the south-

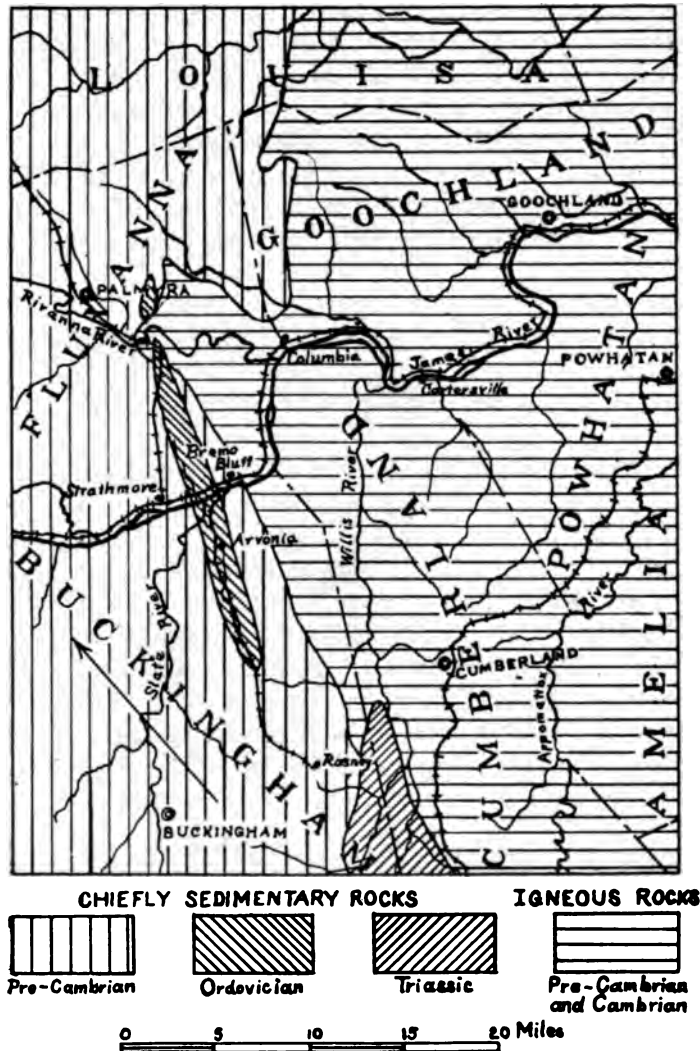


Fig. 1. Sketch map showing areal geology in the vicinity of the Arvonian slate belt.

east at angles varying between 45 and 90 degrees. While the crustal movements were still in progress, large masses of granitic magma were intruded into the older formation, the period of igneous activity continuing until after the compressive movements had practically ceased. These igneous rocks form the great batholith occupying the eastern portion of the area. They are members of the granite-diorite family, and while those that are of earliest crystallization are highly schistose, the rocks that were last to solidify are practically massive. The contact with the pre-Cambrian sedimentary rocks is marked in most places by a belt of pronounced contact metamorphism.

During Cambrian and early Ordovician times the region was subjected to extensive denudation, the products of erosion probably going to build up the Cambrian formations² lying just northwest of the area shown in Fig. 1. This period of denudation resulted in the exposure of the deep-seated granitic rocks, and it was upon the eroded surface of both the earlier formations that the Ordovician sediments were laid down.

The Ordovician sediments consisted almost exclusively of five muds of terrigenous origin; the limited thickness of the coarser materials at their base indicating that subsidence was probably rapid, while the presence of tuffaceous beds shows that the movement was accompanied by more or less volcanic activity. Crustal movements occurring after the deposition of the beds altered the finer sediments to highly crystalline slates and compressed the formation into the synclinal fold to which the slates owe their preservation. They are extensively faulted and crumpled into innumerable minor folds, but the synclinal structure of the slate belt as a whole is shown by the presence of the basal conglomerate in contact with the older rocks along either side. The slates are of high quality for roofing purposes, and have been extensively quarried for many years in the vicinity of Arvon.

The exposures of Ordovician rocks are for the most part confined to a long narrow belt, averaging about half a mile in width and extending approximately twenty-two miles in a southwesterly direction. Where the Rivanna River crosses the belt the Ordovician sediments have been completely worn away, exposing the underlying granite. (See Plate 4, Fig. 1.) There is a small outlying area of slate about

²Thomas L. Watson, "A Geological Map of Virginia," *Virginia Geological Survey*, 1911.

four miles southwest of Palmyra, which has become separated from the main belt by folding and erosion, and there may be some others. The seismic disturbances have originated along the line of this slate belt.

The Arvonian slate belt is in direct line of strike with the similar Ordovician slates of the Quantico belt, which has been traced for a distance of forty miles in Prince William, Stafford, and Spotsylvania counties. The two belts are separated by a distance of only thirty-five miles in Spotsylvania, Louisa, and Fluvanna counties, and it is believed that the basin in which they were deposited was a continuous one.³ No other rocks of Ordovician age have been discovered in the Piedmont region of Virginia, and it is unlikely that they ever covered an extensive area east of the Blue Ridge. The distribution and structure indicate that the slates were laid down in a long, narrow, trough-like depression, which was probably diastrophic in origin.

During Carboniferous times the area was subjected to extensive peneplanation, which was not interrupted until the surface was warped or faulted to form the basins in which the Triassic sediments were laid down. The deposition of these sediments was accompanied or immediately followed by the intrusion of diabase dikes. Since Triassic times the surface has been slightly elevated and there has been a little minor folding and faulting, but no important crustal movements seem to have occurred. Degradation has continued without interruption down to the present day.

The close folding and faulting of the Arvonian slates are well shown in the bluffs, found on the north side of James River, which furnish an almost continuous section across the belt. The cleavage of the slates commonly coincides with the bedding and dips toward the southeast at high angles; but in many places the planes of cleavage and bedding, while similar in strike, intersect along the dip. This lack of uniformity is in marked contrast to the isoclinal dip of both bedding and schistosity in the pre-Cambrian schists on either side of the slate belt. Occasionally the slates show two directions of cleavage intersecting at oblique angles; one being the ordinary slaty cleavage due to pressure, while the other is probably slip cleavage due to minute faulting.

³Thomas L. Watson and S. L. Powell, "Fossil Evidence of the Age of the Virginia Piedmont Slates," *American Journal of Science*, 4th Series 31, 33-34, January, 1911.

All of the faults observed in the slate are strike faults, but along their dip several of them intersect the cleavage planes of the slate, thus furnishing evidence that their formation was subsequent to the crustal movements which induced the slaty cleavage. In the fault shown in Plate 4, Fig. 2, the drag of the cleavage planes clearly indicates that in this case the faulting was normal with a relative downthrow on the eastern side.

None of the faults seem to have produced any noticeable topographic effects. It is true that the slate belt is marked by a long line of straight, narrow valleys, such as the Hunts Creek valley in which Arvonnia is located; but these valleys are probably to be explained by the lesser resistance to erosion offered by the slates as compared with the quartzites and quartz-mica schists forming the divides on either side.

The writer believes that the recent earthquakes originating in this area have probably been caused by slight displacements along one or more of the faults. The frequent recurrence of shocks, and their localization along the strike of the slate belt, suggests that some sort of progressive crustal movement is now taking place and that the resulting strains are relieved by occasional displacements along this line, which has been the locus of several important movements in the past. If this be true we may expect occasional disturbances in the future, and a careful study of these ought to furnish some information concerning the character of the movements which may now be in progress.

While a number of earthquakes have been recorded in Virginia during the past century, very little information concerning them is obtainable at this date, and in only a few of the more recent ones is it possible to determine even approximately the locus of the disturbance, the intensity, or the area affected. A severe earthquake was recorded in Richmond as early as August 23, 1802, but nothing is known regarding its origin. In the summer of 1833 the central parts of Virginia were disturbed by one of the severest shocks felt in the state during the nineteenth century; and from the limited information at hand, it seems to have been most severe near the axis of the Ordovician slate belts. Mr. T. W. Baker informs the writer that he distinctly recalls this shock, although he was only a small boy at the time. According to his statement he was on his way to school, about eight miles from Louisa county courthouse, when the earthquake

occurred, and it was so violent that the fences along the road were visibly shaken.

In referring to this earthquake, Featherstonhaugh mentions a Mr. Holliday, living in Louisa county, who collected information concerning the shock, and who thought "that his own residence was a sort of central point toward which all the rumblings converged." Although the earthquake was not sensible at Hot Springs, Bath county, Dr. Goode, who was sitting near the "Freestone Spring" at the time, noticed a disturbance of the water followed by a violent ebullition of gas which made the water turbid. He was struck by the unusual phenomenon, but did not know of the earthquake until several days later.⁴ The escape of the gas may have been due to the passage of earthquake waves which, by compressing openings in the rocks, forcibly expelled the gases.

A severe shock is said to have been felt in Nelson county and elsewhere in the Virginia Piedmont region, in September, 1852; but as nothing is known concerning the intensity of the shock in definite localities, it is impossible to determine the location of the origin.

During the year 1875 several earthquakes were felt in Virginia, and all of them appear to have had their origin in the region of the Buckingham county slate belt. The writer obtained most of his information concerning these disturbances from letters and newspaper accounts written at the time, and especially from the descriptions published in the *Daily Dispatch* of Richmond, Virginia. The first of the earthquakes occurred on March 10th, and seems to have been of low intensity. It was reported from Goochland county, and is referred to by Prof. Charles H. Winston in a newspaper article.

The next earthquake of that year, recorded on December 22d, at 11:45 p.m., was by far the most severe of the series, having a maximum intensity of VII or higher in the Rossi-Forel scale. In attempting to locate the epicenter of the disturbance, intensity data relating to over fifty widely separated localities were plotted on a map and isoseismals drawn. The isoseismals are elliptical in form, the longer axis extending in a northeast and southwest direction, and they are concentric about the Buckingham region, indicating that the origin was in that vicinity. The shock was felt over an area of about 50,000 square miles.

⁴G. W. Featherstonhaugh, "Excursion Through the Slave States," New York, 1844.

The earthquake was perceptible at points 150 miles distant from the origin in a northeast direction, being reported from Baltimore, Annapolis, and Sandy Springs, Montgomery county, Maryland; toward the southwest it was felt in Greensboro, North Carolina, 135 miles away; the shock was distinctly felt at Fortress Monroe and in Norfolk, 120 miles to the southeast; and in a westerly direction it was not felt beyond Greenbrier, White Sulphur Springs in West Virginia, distant about 110 miles from the origin. In a brief account of this earthquake Professor Rockwood, quoting from a report of the U. S. Signal Service, mentions that the shock was felt "about 11:30 at New Market, Ind.,"² but, in view of the information obtained from other sources, this statement must be erroneous. If a shock was felt in Indiana at that time, it probably had an independent origin.

No detailed information is now available concerning the intensity and character of this earthquake in the immediate vicinity of the origin. A report from Fluvanna county states that there were five distinct shocks at close intervals, and that they were sufficiently violent to awaken all sleepers. The shocks were strongly felt in Goochland and Powhatan counties; bricks are said to have fallen from several chimneys. At McRae in Cumberland county, sixteen miles southeast of Arvon, the sound seemed to approach from the northwest. People were awakened, many becoming alarmed; and the chickens in the yards seemed to be greatly disturbed. At Farmville, twenty-seven miles south of Arvon, the first shock was felt at 11:45 p.m. and a second one about fifteen minutes later. Everyone in the vicinity was awakened and some were frightened. In Louisa three shocks were reported, separated by intervals four minutes and nineteen minutes respectively; the first having a duration of about forty seconds, the second of thirty seconds, and the third not more than fifteen seconds. At Manakin, near the lower end of Goochland county, shingles were shaken from the roof of a store, and many lamps thrown from shelves and broken.

In Richmond, a little more than fifty miles east of Arvon, three distinct shocks were felt. According to Mayor Kelley, the first occurred at 11:44, the second after an interval of five or seven minutes, and the third twelve to fifteen minutes later. All began with a sound like a rising wind, which increased in violence until the shocks were

²C. G. Rockwood, Jr., "Recent American Earthquakes," *American Journal Science and Arts*, 3d Series, 12, 29-30.

accompanied by a loud roar. The movement seemed to be from east to west. Plastering fell in several houses, and at least a fourth of the inhabitants are said to have rushed into the streets. The shock was felt by several who were aboard boats on the James River. At Staunton and Waynesboro, about fifty miles northwest of Arvonion, the shock was reported as violent; knives, forks and other objects being thrown from shelves.

Several after-shocks were recorded, but they seem to have been sensible only in the vicinity of the origin. Several slight shocks were felt at Cedar Point, Goochland county, on the night of December 23d, and on the same night two shocks were reported from Louisa. A report from Powhatan states that a decided shock was felt at noon on December 26th. It was observed on both sides of the river, but caused no alarm. Because of the lack of ready communication with the outside world, as well as the low intensity of these after-shocks, they were recorded from only a few points within the area, making it difficult to fix their exact place of origin. Most, if not all of them, however, probably originated within the slate belt.

From 1875 to 1907 no earthquakes are known to have had their origin in this section, though several severe shocks, such as the Charleston earthquake of August 31, 1886, and the Giles county, Va., earthquake of May 31, 1897, were generally felt. On February 10, 1907, at 7:30 p.m., a slight shock (intensity about III, R.-F.) was felt in the vicinity of Scottsville, but it was not noticed at Arvonion or New Canton.

On the following day, February 11th, at 8:22 a.m., occurred the severest earthquake recorded at Arvonion in recent years. Although near the origin, in the vicinity of Arvonion, the shock had an intensity of VI, R.-F., it was felt over an elliptical area of scarcely 6,000 square miles. The shock is variously described as lasting from twenty to thirty seconds, and it was accompanied by a loud grating or roaring noise, which slowly subsided. Nearly every one ran out of doors; the negroes, especially, were much terrified. The movement seemed to be from north to south. Furniture and other objects were displaced. Several residents thought that they felt a second shock at 8:45 a.m.; but if so, it was so slight that it was not generally noticed.⁶

⁶Rev. Plummer F. Jones, of Arvonion, furnished the writer with much information concerning the earthquakes of February 11, 1907, May 8, 1910, and August 7, 1912.

An observer at Nuckles, about six miles southwest of Arvonnia, states that the shock appeared to come from the north and was preceded by a sound like a heavy wind or distant thunder, which lasted until after the earthquake had receded. Windows and chinaware were rattled, but no damage done. At Ashley, twelve miles southeast of Arvonnia, where the shock is said to have lasted thirty seconds, a chimney was cracked; at Buckingham, fifteen miles southwest of Arvonnia, a window glass in a store was broken; and at Columbia, eleven miles southeast of the origin, the shock caused many people to run from their houses. In Charlottesville, twenty-five miles northwest of the origin, breakfast dishes rattled on the tables. Mr. F. W. Reid, Assistant at the McCormick Observatory, University of Virginia, recorded the shock at 8:23, the duration being about twenty seconds. The shock was felt by several residents of Barton Heights, a suburb of Richmond, but was not reported in the city itself.

The next seismic disturbances to affect the Virginia Piedmont region were the Powhatan earthquakes of August 23, 1908, but these shocks do not seem to have been felt at Arvonnia. According to Dr. H. F. Reid, the area within which the earthquakes were sensible was elliptical in shape, having a diameter of thirty miles north and south, and fifteen miles east and west, with a total area of 450 square miles. Shocks were recorded at 3:30, 4:30 and 10 a.m.; and 2:30 and 8 p.m. The strongest shock, which was recorded at 4:30 a.m., had an intensity of IV, R.-F.¹

An earthquake with an intensity of V, R.-F., occurred on May 8, 1910, at 4:10 p.m., the origin being located in the slate belt in the immediate vicinity of Arvonnia. There was a single distinct shock lasting about thirty seconds, which was accompanied by a rumbling noise. The shock was felt by practically every person in the vicinity, and the noise was noted by many who were out of doors; for, since it was Sunday, the slate quarries were not in operation and every thing was quiet. The shock was distinctly felt at Cartersville, where it was severe enough to rattle windows, and it was noticed by a few in Charlottesville, twenty-five miles northwest of Arvonnia.

On August 7, 1912, at 8 p.m., another earthquake occurred. At Arvonnia it had an intensity of IV or V, but it was felt within a radius of not more than twenty miles. The vibrations appear to have been

¹Private communication from Dr. Harry Fielding Ried, special expert in charge of earthquake records for the United States Geological Survey.

north and south. Dishes and other movable objects were caused to rattle. The shock was distinctly perceptible at New Canton and Bremono Bluff, where it was preceded by a roaring noise like a blast in the quarries.

Conclusions.—From the data given above it is evident that the Arvonian slate belt has been the locus of repeated seismic disturbances, which are undoubtedly caused by differential movements along faults. The axis of the Ordovician slate belts is probably a line along which there have been important crustal movements in the past, and the folding and fracturing of the rocks may have made it a line of weakness. Accumulative strains due to slow crustal movements are most readily adjusted by displacements along this line of weakness. The strength of the slates, which is less than that of the older rocks of the area, may be another factor influencing the location of the displacements. Judging from the past history of the district we may expect earthquakes to occur from time to time in the future, though most of them will be of feeble intensity, and do little or no actual damage. It is to be hoped that an accurate record may be kept of future disturbances, as a study of them may furnish some clue to the nature of the crustal movements that are now in progress.

UNIVERSITY OF SOUTH CAROLINA,
COLUMBIA, SOUTH CAROLINA.

teachers with their pupils, and even children, were ungrudgingly received. In spite of his exacting labors, he seemed ever ready to show his instruments and talk about his work with the most casual visitor.

Some, perhaps, may suggest that Milne was wanting in sympathy with the work of co-ordinating the results of other organizations than his own; and it may be admitted that his Pegasus did not run well in harness. But it must be remembered how, from the first, he had been accustomed to bear all the weight and responsibility of great enterprises on his own broad shoulders. John Milne's death is indeed a great calamity for science—how great will only be realized when the attempt is made to supply his place.

J. W. J.

THE CONTINUATION OF MILNE'S WORK IN SEISMOLOGY²

A well-informed writer in *The Times* of August 7th has insisted on the importance of securing the continuity of the late Professor Milne's great scheme of seismological observation and research. Milne himself always fought strenuously against his own undertaking being absorbed and lost in any international scheme. It is true that in connection with the international system there are some admirably equipped laboratories, furnished with a variety of instruments of extreme delicacy and sensitiveness; but the establishment of one of these is so costly an undertaking that such laboratories can never become numerous. Milne's aim was to secure a great number of seismological stations, scattered as widely as possible over the globe, each furnished with instruments of the same pattern, the records of which would be strictly comparable. The practical results which have been secured by Milne's scheme have shown that the comparatively simple type of apparatus which he advocated has furnished just such an observational basis for research as is necessary. Milne, at the outset, saw in the British colonies and dependencies the means for a wide extension of his scheme—though he by no means limited his efforts within the Empire. It would, indeed, be a disgrace, as well as a misfortune, to British science if the great undertaking originated by Milne were to suffer dislocation, or to be lost by absorption in any other scheme; and, at the same time, no more worthy monument to Milne's enterprise could be imagined than the maintenance and development of the system of observations to which he devoted his genius and energy, and for which received little encouragement during his lifetime.

It is a very fortunate circumstance that the British Association is holding a meeting so shortly after Milne's lamented death, for no time must be lost if his invaluable organization is to be rescued from the ruin which is threatened by the loss of its master-spirit. From the year 1841 onward, the association has been the nursing mother of seismological science in this country, and has helped Mallet, and afterwards Milne, by contributions from its funds, and especially by publication of their results. Milne was always ready gratefully to acknowledge the great aid afforded to him by the association, and devoted much

²*Nature*, August 14, 1913, p. 610.

of his time during the last year of his life to drawing up a valuable index to the numerous contributions to seismology scattered through seventy-two volumes of the association's reports. This index is now in type, and will be presented at the forthcoming Birmingham meeting. It may be hoped that on this occasion a means may be found for consummating the great aid which the association has always furnished to seismological science, by inaugurating an effort to place Milne's system of observation and research on a sound and permanent basis. It may be suggested that as a national system of meteorological observations has been evolved from the meteorological committees of the British Association, a national seismological scheme may, in like manner, be developed from the association's committees on the subject.

On August 8th a second letter appeared in *The Times* from the president of the Royal Society, strongly urging the importance of continuing Milne's organization, and making it a national undertaking. Sir Archibald Geikie, besides bearing eloquent testimony to Milne's genius and enthusiasm as a scientific worker and his loveableness as a man, is able to quote from a letter just received from Prince Galitzin, the president of the International Seismological Association, in which it is asserted that Milne "through his most important investigations set seismology on a firm scientific basis, founded upon instrumental observation," that "he can duly be considered as the real founder and promoter of this new and important branch of geogryphics," and that the continuation and development of his great work "would be the best monument to his memory."

J. W. J.

SEISMOLOGICAL NOTES.

Record at St. Louis.—The Bulletin of St. Louis University, Volume 9, Number 2, contains a list of the earthquakes recorded by the instruments of that institution during 1912. Forty-eight are given.

Earthquake in the Philippine Islands.—Rev. M. Salerna Maso of the Manila Observatory has sent a note and sketch map of the earthquake which occurred in the Islands of Mindanáo and Visayas on March 14, 1913, at 8:42 o'clock M.P.T. In the eastern part of Mindanáo a maximum intensity of IX was reached. Numerous after-shocks were experienced up to April 30, 1913. "On the 24th, 25th, and 26th of April the shocks felt in the northern part of the Agusan Valley and in the peninsula of Surigao, according to the popular impressions, numbered more than two hundred, but none exceeded intensity VII."

Point Loma, California.—Our colleague, Fred. J. Dick of the Meteorological station of Raja Yoga College, sends the following report of shocks recorded in the observatory at Point Loma:

Between three and four o'clock in the morning of April 21, 1913, a slight shock was recorded by a movement of about one and a half mm. north-south, and one mm. east-west.

Tremors recorded before 8 a.m. May 8th for the preceding twenty-four hours had a diameter of one mm.

Tremors during the twenty-four hours preceding 8 a. m. May 15, 1913, about one mm. west-southwest and east-northeast.

The sei-moscope is a two-component C. D. West without magnification.

Distinct tremor felt in Ottawa, Canada.—Dr. Walter F. Ferrier sends notice of an earthquake shock felt at Ottawa, Canada, at 7:29 o'clock on the evening of April 28, 1913. The shock was reported to have lasted for fifteen seconds and Dr. Klotz, Dominion Astronomer, stated that the tremors were exceedingly well defined and distinct. Corresponding shocks were felt at Montreal and in the St. Lawrence

Valley. From reports received the intensity is estimated at IV, R.-F. scale. Seismograph records were obtained both at Ottawa and Montreal.

Note of this sharp earthquake was made in this BULLETIN for June, 1913, stating that it was the heaviest shock ever experienced in the northern part of the state of New York.

Earthquakes at Rome, Italy.—The series of earthquake shocks which had been causing alarm in many parts of Italy during the early part of May, 1913, continued to May 17th, when two severe volcanic disturbances rocked the hills to the north of Rome, both shocks being felt in the upper part of the city.

One of the huge blocks in the ruined temple of Bacchus was dislodged from its base and broken. In the city the uneasiness caused by the earthquakes was increased by reports of numerous cases of Asiatic plague. In the lower Alps many of the peasantry were greatly excited by the shock.

In Frascati, Italy, on May 16th, three severe tremors rocked the city and environs over a radius of several miles. The shock caused a large congregation, celebrating the city's feast day in the church of San Pietro, to become panic stricken, and three women and five children were trampled to death.

Lesser earthquakes were reported from many parts of Italy at the same time.

A record at Santa Clara University Observatory, California.—Rev. J. S. Ricard of the University of Santa Clara gave out the following on May 30, 1913:

"A seismic disturbance was recorded this morning. The indistinctiveness of the first and second waves, which were obscured by uniform pulsations, due to the present storm in the south and southeast, renders estimates of distance impossible.

"The record is in the form of a curve of sines, which indicates a distance at least equal to the radius of the earth. The first clear displacement of the stylus produced by the long waves indicates a westerly origin. Undoubtedly the seat of disturbance was between 4,000 and 5,000 miles west of Santa Clara."

A corresponding record at New York.—An earthquake shock, apparently at a great distance from New York, south-southeast, was

recorded by the seismograph at the American Museum of Natural History on May 30, 1913.

Continued disturbances in East Tennessee.—In this society's BULLETIN of June, 1913, notes were published on shocks felt in eastern Tennessee. Since that time reports of similar disturbances have been received from the same region.

Dr. Charles P. McNab of Knoxville, Tennessee, reported a slight shock, accompanied by a rumbling sound which lasted several seconds, at one o'clock on the morning of May 2, 1913, near Madisonville, Tennessee. As Dr. McNab was riding in a buggy at the time of the shock he could not estimate its intensity.

Shock at Humboldt, Tennessee.—A report comes from Nashville, Tennessee, of an earthquake felt by the residents of Humboldt, Tennessee, at 9:30 o'clock on the morning of June 9, 1913. "There was a rumbling sound, a considerable quiver of houses for an instant, and it was all over."

Earthquake at Sofia, Bulgaria.—Belated reports came June 16, 1913, to the effect that over one hundred bodies had been taken from the ruins of the houses demolished in the earthquake at Tierrava and Govinia-Orchovitz. In the latter place many buildings were destroyed. Up to June 20th the shocks still continued.

San Jose, California.—The seismological observatory of the University of Santa Clara reports that the horizontal seismograph recorded a long-distance earth-shock beginning at 9:09 o'clock and ending at 11:07:30 o'clock on the evening of June 26, 1913. The period was 1.5 seconds. Professor A. J. Newlin places the epicenter in the neighborhood of 3000 kilometers in a northwest direction. It seems to be another of the Aleutian islands disturbances.

The Roman earthquake of June 28, 1913.—Extensive earthquake shocks occurred in the southern part of Italy on June 28, 1913. Houses were damaged in many villages, and some of the inhabitants were injured.

On June 28, 1913, for the first time since 1906, flames were observed shooting up from Mount Vesuvius. The uppermost crater emitted a dense cloud of smoke, which frequently showed striking reflections of flames lower down, with an occasional eruption of fire.

Professor Mercalli, director of the observatory, reports that the lava streams were becoming continuous. He expressed the opinion that the seismic movement on Mount Vesuvius had no connection with the earthquake in the Calabria district, although he considered the coincidence noteworthy.

Later shock in Southern Italy.—From Messina, Italy, comes the report of a slight earthquake shock on July 2, 1913, and lasting only a few seconds. Underground rumblings caused considerable alarm, and many of the inhabitants fled from their residences into the open fields.

San Juan del Sur, Nicaragua.—Earth-shocks, of more or less violence, continued up to July 17, 1913, in Nicaragua, principally in the departments of Managua and Masaye. In Masaye several houses were destroyed, and the volcano Santiago was reported to be active.

Kingston, Jamaica.—Mr. J. F. Brennan of the Government Weather Bureau at Kingston, Jamaica, writes:

"A fairly intense earthquake was experienced in Kingston on July 25, 1913, at 10:45:33 a.m., and a good record of the oscillations was obtained from the Gray-Milne type of seismometer established on the lower floor of the Public Works Office, Port Royal street, Kingston."

Particulars as follows:

"Intensity No. III; direction N 26° E to S 26° W; greatest horizontal movement 0.063 inch; duration about ten seconds; appeared to be a double shock; was not accompanied with much rumbling sound; chiefly oscillatory.

"Estimating by its direction, this earthquake apparently may be identified with one of our epicenters lying in the Port Royal Mountains, as described by Mr. Maxwell Hall in his 'Fourth Report on Earthquakes in Jamaica,' No. 365, W. R., issued May, 1909, and not to the epicenter lying to the SE of Kingston, which is supposed to have been the origin of our great earthquake of January 14, 1907.

"The earthquake of to-day is the greatest occurring since the severe shock of January 2, 1908 (the year succeeding the great shock), which measured 0.314 inch. The next recorded, in point of intensity, 0.096 inch, occurred on April 13, 1907, at 7:08 a.m.

"It may be noted that the preceding shocks, noted for the past few years, from the year 1909 have been of much inferior intensity, and the frequency is as follows:

1909.....	11	shocks
1910.....	3	"
1911.....	7	"
1912.....	5	"
1913 (part).....	1	"

There was also a shock of less intensity on August 13, 1913, at 10:03 p.m., the extreme horizontal movement being 0.009 of an inch, and the direction NNW to SSE.

Both of the above shocks were also apparently experienced in the eastern part of the island.

A slight earthquake on Mt. Rainier, Washington.—About 8:15 o'clock on the morning of July 29, 1913, two earthquake shocks shook Mount Rainier and were felt over an area of more than a hundred square miles. The shocks appeared to be the strongest at Lewis in Lewis county, and were noted at Elbe and Etonville, in Pierce county.

The disturbance is said to have lasted about half a minute. Ethan Allen, superintendent of the National Park, Washington, says the shocks came close together and were so violent that there could be no doubt about their being of a seismic nature. From reports received the shock had an intensity of between V and VI of the Rossi-Forel scale.

Earthquake in Sicily.—A strong undulatory perpendicular earthquake caused a panic among the population of Messina, Sicily, early in the day of September 2, 1913. The shock lasted six seconds, causing the people to abandon their houses and flee to the open streets.

Another slight earthquake was felt in Messina the morning of September 4, 1913. It lasted five seconds, and created a panic among the inhabitants.

REVIEWS.

THE ORIGIN OF EARTHQUAKES. By Charles Davison, Sc.D., F.G.S. *Cambridge University Press*, 1912, 144 pages.

This little book, one of "the Cambridge Manuals of Science and Literature," is written in a simple, clear style, with only a moderate use of technical terms so that it may be very readily understood by the layman reader. There are twelve chapters and some two dozen simple and helpful illustrations.

The titles of the chapters are: I. The earthquake phenomena. II. Earthquakes and the growth of faults. III. Simple earthquakes and their origin. IV. Twin earthquakes and their origin. V, VI, VII. Complex earthquakes and their origin. VIII. Fore-shocks and their origin. IX. After-shocks and their origin. X. Sympathetic earthquakes and their origin. XI. Earthquake sounds and their origin. XII. Distribution of earthquakes.

The descriptions of the various kinds of earthquakes, simple, twin, and complex, are illustrated by numerous examples of shocks that have occurred in recent times in various countries.

One of the most interesting chapters in the book is that on earthquake sounds. There is much conflicting evidence in regard to sounds accompanying earthquakes. This is due to the fact that the sounds are of extraordinary depth, too low to be heard at all by some ears. To quote from the author: "Still more decisive is the evidence furnished by the fact that the same sound is heard by some observers and not by others. One will describe the sound as like the rumbling of a heavy traction-engine passing, or as louder than any thunder; another in the same place will be equally positive that the shock was unaccompanied by sound. Not only people in the same town, but persons in the same house, and even in the same room, differ in this respect."

Opposite page 130 is a map of the world, showing twelve principal regions of seismic disturbances. Six of these are located in the oceans, five on the shores of the Pacific, while only one is completely continental, that being located in southwestern Asia and southeastern Europe.

This little manual can be heartily recommended to anyone wishing to obtain a clear exposition of the fundamental principles of the science of seismology.

S. D. TOWNLEY.

THE SORSOGON EARTHQUAKE. By Rev. Miguel Saderra Maso, S.J., *Weather Bulletin*, November, 1912.

The Rev. Miguel Saderra Maso, S.J., Assistant Director of the Philippine Weather Bureau, describes in the *Weather Bulletin* for November, 1912, the earthquake which occurred in the Province of Sorsogon, southeast of Luzon, on November 8, 1912. There were three slight shocks from early morning till midday; and in the afternoon at 15 h. 48 m. there was another shock. Seven minutes later (15 h. 54 m. 30 s.) the principal shock occurred. The damage done was considerable. The High School, a building of squared concrete blocks bound to each other with iron clamps, was cracked in many places, while the portico of reinforced concrete was also fissured. In the Constabulary Barracks, a new stone building, the east wall fell out, other walls were cracked, and the old stone fence facing north was thrown down. Practically all the old stone buildings in the town were badly damaged, but Father Maso states that the construction of these buildings was faulty. A large fissure opened in the road between Sorsogon and Gubat, six kilometers east from Sorsogon; and there were many landslides among the hills. While the water in the bay was somewhat agitated, there was no seismic wave.

Father Maso draws the isoseismic lines and shows that the meizoseismic area comprised the southern two-thirds of the land that stretches from the Bay of Sorsogon to the Gulf of Albay, occupied by an irregular series of hills and volcanic cones, known as Pocdol. The northern coasts appear to have been beyond the meizoseismic area.

A detailed list of the preliminary tremors, foreshocks and repetitions is given. The disturbance was in effect the maximum phase of a seismic period that lasted from November 5th until December 26th. The seismographs at Manila and Baguio, distant from the epicenter 360 and 520 kilometers, recorded all the seismic shocks that had an intensity of IV or more. The principal earthquake was recorded in all the observatories of the Far East, of Asiatic Russia,

and in some observatories of Europe, though in these latter the traces were weak. Father Maso gives the following table:

	h.	m.	s.
Manila, P.I.....	7	54	30
Baguio, P.I.....	7	55	00
Taihoku, Formosa.....	7	56	47
Zikawei, China.....	7	57	39
Osaka, Japan.....	7	58	55
Irkutsk, Russia.....	8	01	20
Aachen, Germany.....	8	29	(eL)
Hamburg, Germany....	8	39	(eL)
San Fernando, Spain... 8	44	(eL)	

Father Maso's conclusions are of such interest that we reprint his remarks in full:

Soon after the earthquake, and before the data we now possess had come to hand, we published in the local press a short article on the subject, in which the earthquake was classified as local and superficial. "Taking into consideration its small area," it was said, "we believe that we have to deal with an earthquake caused by the caving in of underground caverns, due to either the dissolution of the rock by subterranean water which rises in Manito and in other places as mineral and thermal springs, or to old volcanic action." After a more detailed study of the reports that came to hand after the above article was written, we are of the opinion that the view expressed must be modified. For the fact that the earthquake was registered, though faintly, in Europe at distances of more than 10,000 kilometers can not be reconciled with the idea of a local and superficial earthquake; and the numerous preliminary tremors and aftershocks that occurred during the seismic period also militate against this idea. Again, the meizoseismic area has an elongated form in the direction ESE-WNW along the stretch of land which lies between the isthmus of Sorsogon and the Gulf of Albay, and is consequently more extensive than was supposed when the first reports came in. If we now take the geological map of the Philippines, as published by Dr. W. D. Smith, Chief of the Division of Mines,¹ and from which were taken the geological indications reproduced in our map, we shall see that the major axis of the meizoseismic area almost coincides with the line of contact between the lands of volcanic origin of the N and the sedimentaries of the S of Sorsogon; and, moreover, that this line is not coterminous with the district, but seems to be a prolongation to the ESE of the seismotectonic line of the Camarines, which in this case would reach as far as the sea after passing through the lowland of Sorsogon and Gubat. From this we think that it is possible to deduce that the recent earthquakes of Sorsogon were due to movements or dislocations in the eastern part of the Camarines seismotectonic line, and hence were of a tectonic character, like the ones that took place along the same line, but farther west, in 1907. This deduction is all the more probable

¹The Mineral Resources of the Philippine Islands, 1909.

BULLETIN OF THE U. S. COAST AND GEODETIC SURVEY, 1913. Results of observations made at the Observatory at Cheltenham, Maryland.

A Bosch-Omori seismograph has been in operation at Cheltenham since November, 1904. It consists of two horizontal pendulums, one recording north-south motion and the other the east-west motion.

The earthquakes have been registered and tabulated from January 3, 1911, to December 7, 1912. The principal earthquakes recorded were that of January 3, 1911, which had an amplitude of 59 millimeters n. s.; that of June 7, 1911 (the Mexican earthquake), which had an amplitude of 65 millimeters n. s., and 12 millimeters e. w.; and that of July 7, 1912, which recorded 23.9 millimeters in both north-south and east-west directions.

ÉTUDES SUR LA SÉISME DU RIBATEJO DU 23 AVRIL 1909. Par Paul Choffat et Alfred Bensaude. *Commission du Service Géologique du Portugal*. 4to, 146 pp., 4 Planches, 2 cartes en couleurs et 5 dans le texte. Lisbonne, 1911.

The earthquake described in this report had its center on the Tagus some thirty kilometers northeast of Lisbon, and was felt all over Portugal, and even as far east as Madrid, where it had an intensity of VI of the R-F scale. The area affected amounted to 215,000 square kilometers, a remarkably large one for a European shock.

Immediately after the earthquake the minister of public works appointed two commissions, one to study methods of construction in earthquake regions, and another to gather data regarding that particular shock. This last was composed of several members, but eventually the work was done by the two whose names are given.

Those who, like the reviewer, have had experience in gathering earthquake data, will be interested to find human nature behaving pretty much the same in Portugal as it does in other parts of the world when it comes to newspaper reports and to getting answers to questions about earthquakes.

The maps accompanying the report show that the shock was felt on many vessels at sea, and that the highest intensity, between IX and X of the R-F scale, was in the vicinity of the town of Benavente and the villages of Samona and Santo Estevão. This area of

high intensity covers about 425 square kilometers. A comparison with former earthquakes in Portugal shows the disturbance to be the most severe of recent years, and that it was exceeded only by the great Lisbon earthquake of 1755.

The authors note the interesting fact that the earthquake of 1755 has left a profound impression on the popular mind, and that of late years that impression has been further emphasized by the Messina earthquake.

One is tempted to make long extracts from this interesting volume, but it is one that seismologists will wish to read and study. On the whole the report is one of the most interesting we have seen.

J. C. BRANNER.

CATALOGO DE LOS MICROSEISMOS REGISTRADOS DURANTE EL AÑO DE 1911. Estación Seismológica Central, Tacubaya, D. F., Mexico. *Paragones del Instituto Geologico de Mexico*, Tomo IV, numero 1, pp. 33-85.

A catalog of all earthquakes registered instrumentally in the various seismological stations of Mexico is published each year in the "paragones" of the Geological Institute of Mexico. The tables are complete, giving the data usually recorded at such stations. The one appearing under the above title lists 190 shocks registered in the Central Seismological Station, Tacubaya, D. F., during the year 1911.

The majority of the shocks originated at a distance between 200 and 400 kilometers from the observatory.

C. F. TOLMAN.

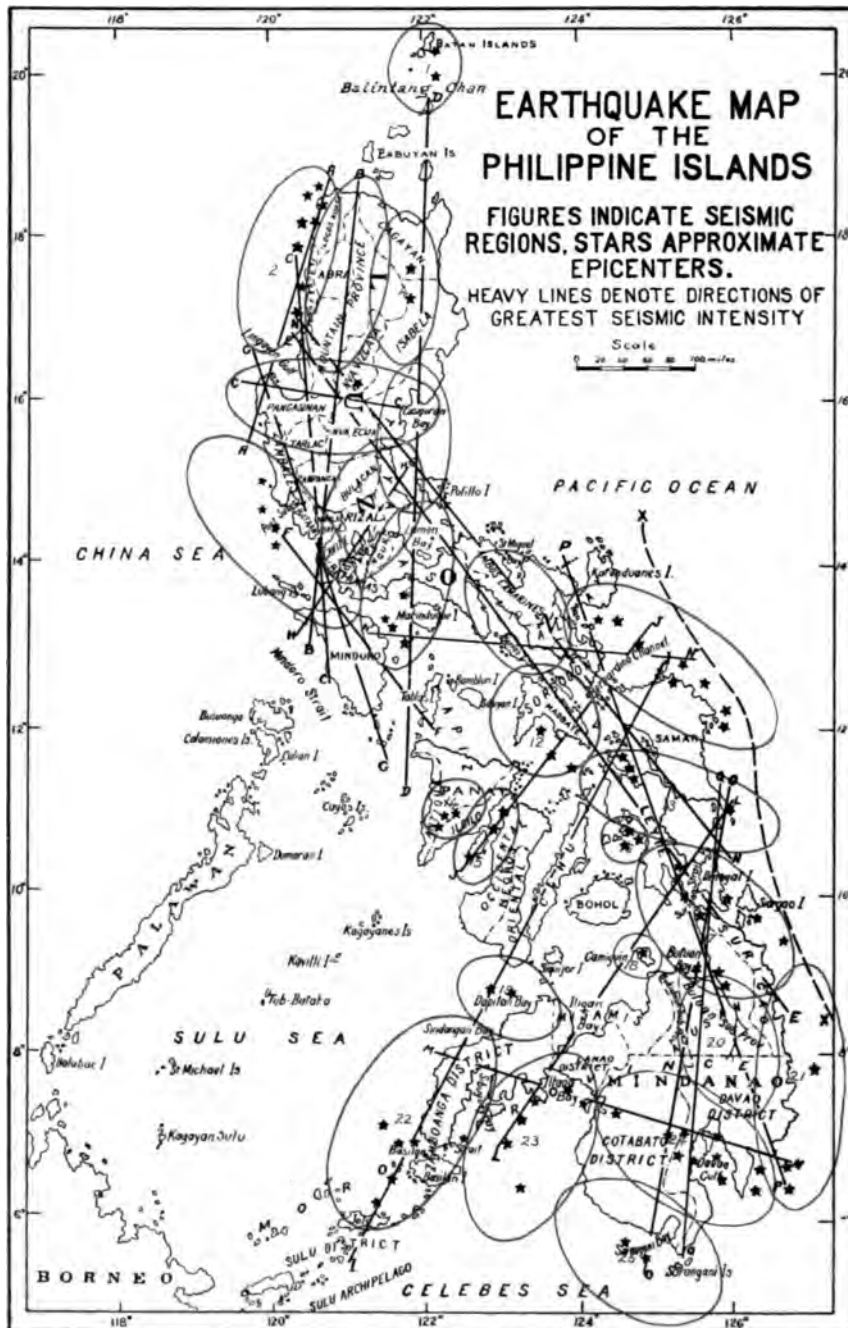
BULLETIN SEMESTRIEL DE L'OBSERVATOIRE MÉTÉOROLOGIQUE DU SÉMINAIRE-COLLEGE ST. MARTIAL. Port-au-Prince, Haiti, Juillet-December, 1912.

Like its predecessors, this bulletin is chiefly occupied with the meteorology of the island of Haiti, but pages 129-139 are devoted to seismology. Pages 130-131 contain some additional notes on the "gouffre" already noted in this BULLETIN. At pages 132-139 Professor Scherer continues his interesting history, and comments on the earthquakes of the island of Haiti.

J. C. B.

ROSSI-FOREL SCALE OF EARTHQUAKE INTENSITIES

- I. **Microseismic shock:** recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
- II. **Extremely feeble shock:** recorded by several seismographs of different kinds; felt by a small number of persons at rest.
- III. **Very feeble shock:** felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- IV. **Feeble shock:** felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.
- V. **Shock of moderate intensity:** felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.
- VI. **Fairly strong shock:** general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.
- VII. **Strong shock:** overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- VIII. **Very strong shock:** fall of chimneys, cracks in walls of buildings.
- IX. **Extremely strong shock:** partial or total destruction of some buildings.
- X. **Shock of extreme intensity:** great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.



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THE RELATION OF SEISMIC DISTURBANCES IN THE PHILIPPINES TO THE GEOLOGIC STRUCTURE.¹

By FR. MIGUEL SADERRA MASO, S. J.,
Assistant Director of the Weather Bureau, Manila, P. I.,
and WARREN D. SMITH,
Chief, Division of Mines, Bureau of Science, Manila, P. I.

In the light of studies of the last ten years, stimulated by the tremendous cataclysms of Messina and San Francisco, entirely new principles have been introduced into the study of seismic disturbances of the crust of the earth. The old centrum theory of Mallet is generally discredited.

Beyond a doubt, many seismic disturbances are due to causes other than vulcanism. Many of the worst disasters we have experienced have nothing to do with volcanoes; and that volcanoes are near by is only a coincidence, or may be explained by the fact that the place where great disturbances in the earth's crust take place is naturally a zone of weakness and where molten material would be expected to seek an outlet. At the time of the Messina earthquakes, Mt. Etna, which can be seen from Messina, was comparatively quiet. The great disturbances at Messina, as is generally known, were due to an adjustment along the line of a great fault in the earth's crust, which is marked by the Straits of Messina.

The work of the Italian Geological Survey has demonstrated that these disturbances are propagated along very definite lines. So thoroughly did the Italian geologists do their work that by superimposing upon a geologic and topographic map of the province of Calabria another map showing the location of cities and all the works of man, with all historical data regarding earthquakes, one can see at once that: (1) certain points are more subject to earthquakes than others; (2) points removed from these lines have suffered less or not at all; (3) at intersections of these lines the greatest disasters oc-

¹ Published with the permission of the Director of the Bureau of Science..

curring. These lines, which follow more or less definite systems, proved to be the projections of various earth lineaments, such as fault lines, joint lines, formation contact lines, and axes of mountain ranges.

The great California earthquake of April, 1906, is a striking example of this. This earthquake was due to a dislocation along the well-known San Andreas rift, and, although the waves from this disturbance were propagated, to varying distances, on both sides, the greatest disturbance occurred along the line of this fault.

When one can indicate a point on a map and say definitely that here the crust of the earth is unstable, seismic geology is shown to be of very great practical interest to humanity in general and to engineers in particular; and especially is it pertinent in geologically young parts of the world, like the Philippine Islands, where mountain building is in progress and where the evidences of recent vertical movement of various portions of the island mass actually can be measured.

Concrete examples of what these disturbances mean are to be had in the earthquakes of Messina, of San Francisco, and the eruption of Taal Volcano.

The people of Messina had been warned repeatedly; but commercial interests were so great that they took no heed of their danger, and consequently millions of dollars' worth of property, as well as thousands of lives, were lost at the time of that disaster. The same is true of San Francisco. The reported property loss at the time of that catastrophe amounted to \$490,000,000.

The disturbances in the region of Taal were primarily due to the volcano; but Taal Volcano is located along a line of crustal weakness, and at that time a very appreciable displacement occurred along one or more lines passing through Taal Volcano. One of these lines ran from the volcano to the coast through the town of Lemery, and the other from Taal Volcano to the barrio of Sinisian, making with the sea a triangular strip several square kilometers in area. The whole block dropped a meter or more, so that the sea washed inland for a distance of a kilometer over the main highway along this coast. The road between Lemery and Sinisian had to be reconstructed. The damage to buildings in the town of Lemery was considerable. Fortunately no very large structures were located along these lines, but, had there been any, the property loss would have been much more

conspicuous. We may not see in our lifetime a recurrence of disasters either at Messina or San Francisco; but the time will surely come when there will be further displacement along these great earth rifts. It is true that there never will be as great disasters in the Philippines, due to the fact that most of the Filipinos live in basket-like houses, which are the very safest at the time of an earthquake. But large engineering works have been constructed, others are being planned, and large public buildings are continually being built; hence it is of vital importance thoroughly to investigate this question in the light of all the data we now possess.

The scope of the present paper is: (1) to outline the physiography and geomorphology of the Philippines; (2) to discuss the kinds and distribution of the rock formations and the major structural features of the islands; (3) in the light of these, to show the origin of each of the important seismic disturbances of the past; and (4) to draw some practical conclusions.

We are of the opinion that most of the seismic disturbances in the Philippines should be attributed not to volcanoes but to displacements along the major structure lines of the Archipelago. In view of the catastrophe of Taal Volcano and of eruptions at other points, like Camiguin and Mayon, the layman is apt to have his perspective altered, and he is naturally prone to attribute certain phenomena to causes which are not causes, but are results of factors not yet ascertained. It should be borne in mind that volcanoes are merely incidents in the growth of the Archipelago. Both volcanoes and earthquakes may be traced to the existence of lines of weakness and crustal displacements. Many earthquakes are due entirely to volcanic phenomena; but we believe that we can prove that *the major earthquakes, and the majority of earthquakes in the Philippine Archipelago, are not due to vulcanism.*

Until the year 1863 nothing was written on Philippine earthquakes.² Even at the present time there exist but few papers based on modern seismologic principles, and all of these have been written during the last ten years.

The Manila Observatory from its foundation as a private institution in 1865 has directed its attention to earthquakes, but for many years its work was confined to segregating and publishing exact

²The more or less accurate accounts of earthquakes which may be found scattered in the histories of the Philippines are not here considered.

monthly observations, without making a complete study of the subject. Its collection of monthly curves, in which are contained the hourly observations of the Bertelli microseismograph, is exceedingly valuable on account of the long period of time covered.

The earthquake of June, 1863, which practically destroyed the city of Manila and many of the neighboring towns and caused the death of more than 400 persons, led to the nomination of a commission to investigate the architectural character of the buildings and the nature of the soil of Manila in so far as these might be a source of danger in the future. As at that time the only engineers were those who were members of the corps of military engineers, the commission was formed from among these; but their work appeared to be limited to the establishment of several more or less successful principles and practical rules, to which the plans of the new buildings to be erected in Manila were to conform.

Ten years later the commander of military engineers, D. Mariano Cortes y Aguillo, wrote a memoir on the same subject.³ Notwithstanding the undoubted merit of this work as a practical guide for architects, little account was taken of it by the authorities, and it was not published until after the earthquakes of 1880. The author discusses the different seismic theories, but without adopting any of them regarding Philippine earthquakes. He concluded, after the examination of the damaged buildings and other existing data, that the most violent seismic movements in Manila are in an approximate north and south direction.

After the earthquakes of 1880 a commission composed of engineers of public works was appointed to study with care the ruins caused by these earthquakes, to point out the defects in the structure of the buildings that had been damaged, and to formulate rules which would be more practical than the ones previously drawn up for the rebuilding and repairing of the city. This second commission, therefore, was not directly concerned with the study of the causes of the earthquakes of 1880, nor of determining the extent and probable epicenter of the same. José Centeno, engineer of mines, was entrusted with this task. His memoir⁴ is one of the best that has been published

³"Los terremotos—Sus efectos en las edificaciones y medios prácticos para evitarlos en lo posible."

⁴"Temblores de tierra ocurridos en Julio de 1880 en la Isla de Luzon," Madrid (1885).

from a descriptive point of view. He personally covered the whole territory in which these earthquakes had been most violent, and hence was able to determine, with the precision possible in such cases, the meizoseismic areas of the three destructive earthquakes that took place from July 14 to 21, 1880.

It is to be regretted that in this investigation, which reflects much credit upon him, he did not direct his observations to the discovery of rifts and faults which would have indicated the nature of the dislocation which took place in the Eastern Cordillera and which were the causes of these earthquakes. He could not prescind from the ideas then prevalent of the relation of earthquakes to volcanoes, and, if he does not actually attribute the July earthquakes to the influence of Taal Volcano, at least he makes mention of several small eruptions which were supposed to have occurred in the same year, as though he wished to indicate in what direction investigations were to be made if there should be an inquiry as to the origin of those earthquakes.

A short time before this, Centeno had been sent on a commission to the Peninsula of Surigao, where several very severe earthquakes had taken place in 1879 and which had left indelible impressions of their violence in the shape of numerous fissures and subsidences. In his report he assigns Mainit Lake as the epicenter of the earthquakes. Like many other writers, he supposed this lake to be an extinct volcano. He could easily have assigned another origin, because the great number of fissures and subsidences along the ridge of mountains, and especially in Point Bilat, which is its extreme northwest extension, made it rather clear that their character was tectonic. It may be that some spasmodic movement had occurred which had closer relation to the slower geological movements in this part of the Island, and it was these the author took cognizance of, since he quotes as proof that the depth of the port of Surigao had changed during the earthquakes of 1879.

Six months had scarcely elapsed since the Manila earthquakes when a large series of seismic movements began in Neuva Vizcaya which lasted from January until November, 1881. Enrique Abella y Casariego, engineer of mines, was commissioned to visit the affected province, to investigate as to what likelihood there was of any greater seismic cataclysm happening in the future, and in such an event, to see if it would be possible to make the inhabitants emigrate to other

provinces not so affected. Abella's work⁵ is a very able and complete study of the local and superficial character of the earthquakes and of their probable duration, and his predictions with regard to their continuance were perfectly realized, for as he prognosticated the earthquakes ceased shortly afterwards, and up to the present no other of any great importance has occurred. In his discussion of the origin of these earthquakes the author shows that he, too, was influenced by the current volcanic theories, and hence searched for possible connections between the Province of Neuva Vizcaya and Mayon Volcano, which a short time before had shown signs of greater activity.

The Pangasinan earthquake of 1892 gave Abella the opportunity of writing another interesting memoir.⁶ In this work he did not limit his studies to the earthquakes, but added many valuable notes on the geology of the Provinces of Pangasinan, Union, and Benguet, thus coming more into line with modern seismologists. Notwithstanding this, when he draws his final conclusions, he places most weight on the existence of volcanic rocks and other volcanic signs and remains, both ancient and modern, as if it were impossible to discover the origin of these earthquakes without resorting to volcanic action either directly or indirectly.

Several other very interesting and useful physico-geologic monographs are due to the indefatigable labors of Abella.⁷

In 1895 Fr. Saderra Maso⁸ published a book on earthquakes in which he did not pretend to give a complete seismologic study, but merely a coördinated collection of data which might serve as a basis for the future study of the earthquakes of the Philippine Archipelago. Many of these data were in the archives of the Manila Observatory and had not been published previously, while others were to be found scattered in histories, periodicals, and other publications.

The only important conclusion he draws is that the *seismic center*

⁵ "Terremotos de Nueva Vizcaya en 1881."

⁶ Abella y Casariego, E., "Terremotos eperimentados en la Isla de Luzon . . . en Pangasinan, Union y Benguet," Manila (1893).

⁷ "Apuntes fisicos y geologicos de Nueva Vizcaya," Madrid (1884). "Rapida descripcion fisica, geologica y minera en bosquejo de la Isla de Panay," Manila (1890). "El Mayon o Volcan de Albay," Madrid (1885). "Emanaciones volcanicas subordinadas al Malinao," Madrid (1885). "El Monte Maquiling y sus actuales emanaciones volcanicas," Madrid (1885). "La Isla Biliran y sus azules," Madrid (1885).

⁸ "La Seismologia en Filipinas," Manila (1895).

dangerous for Manila does not lie in the existing volcanoes south and southeast of the city, but in the eastern range of mountains and especially in the part east-northeast and northeast of Manila.

The same writer⁹ has given accounts of the more important earthquakes that have taken place in the different parts of the Archipelago. During the first period he endeavored as a rule to trace a relation between earthquakes and volcanoes. In the second period—that is, 1900 to 1912—he inclined to the more modern ideas, in certain of his papers,¹⁰ although he exaggerates the importance of volcanic manifestations when he speaks of the different epicenters as regions of greater seismic activity.

Since 1907 this investigator has written several short papers¹¹ on the seismicity of the different regions of the Archipelago as a preparation to a more complete work like the present. In these articles he has attempted to indicate by the alignment of the different epicenters the possible existence of seismotectonic lines, in conformity with the recent principles of seismology.

In 1899, Koto, professor of geology, Science College, Imperial University, Tokio, published a valuable study¹² in which he discusses the different tectonic lines and volcanic belts of the Philippines and their connection with Celebes, Borneo, and the Moluccas. It is a thorough and complete study of great value, and must be taken into account when drawing the tectonic lines of the Philippines.

As a general study of the geology and vulcanism of the Philippines, Becker's report¹³ is the most complete work that has appeared.

⁹ *Monthly Bulletin of the Manila Observatory*, 1897, and from 1900 to 1912.

¹⁰ "Report on the seismic and volcanic centers of the Philippine Archipelago," Manila (1904); "Volcanoes and seismic centers of the Philippine Archipelago," Manila (1904), as part of the census of the Philippine Islands.

¹¹ "The earthquake of Ambos Camarines," *Bulletin P. I. Weather Bureau* (April 19, 1907), (1907), 172; "The earthquakes of the Batanes Islands and Southern Formosa," *ibid.* (1909), March; "The seismic centers of Northern Luzon," *ibid.* (1909), April; "Submarine seismic centers near the coasts of Northern Luzon," *ibid.* (1909), May; "Seismic centers near Western Mindanao and Jolo," *ibid.* (1910), June; "Seismotectonic lines in Southern Luzon," *ibid.* (1911), November.

¹² "On the geological structure of the Malayan Archipelago," *Journal College Science, Imperial University Tokyo* (1893), 5, Pt. II, 2.

¹³ "Report on the geology of the Philippine Islands," *Twenty-first Annual Report U. S. Geological Survey*, Washington (1901).

In it is to be found an excellent résumé and criticism of all the writings on the subject that had been published up to that date.

The names of several Austrian, German, and French geologists and explorers, to whom we owe the first geological data of the Philippines, should also be mentioned. The principal ones are: von Richthofen, Carl Semper, Oebbecke, K. Martin, Jagor, Roth, R. von Drasche and J. Montano. Likewise attention is called to the works of the eminent French seismologist, Montessus de Ballore, who published many articles on Philippine earthquakes during the years 1895 to 1901. In one of his books¹⁴ he gives a summary of these articles on the earthquakes of the Philippines. This author must be considered as the first to apply to this Archipelago the principles of modern seismology, by referring its earthquakes not so much to imaginary volcanic agencies, as previous authors had done, but to the principal and geological accidents,—in other words, to tectonic lines. Hence the chapter referred to above must in justice be reckoned the first and most important contribution to the study of Philippine seismology.

SUMMARY OF THE PHYSIOGRAPHY OF THE PHILIPPINE ISLANDS.

To present a clear idea of the underlying causes for seismic disturbances in the Philippine Islands, it is necessary to make some general statements. The Philippines Islands form a link in the chain of outliers of the old Australasian continent. According to the "horst" theory of the formation of continents and ocean basins, the Philippine Islands lie at the very edge of the Asiatic horst. In June, 1912, the German survey ship Planet sounded to a depth of 9,780 meters about sixty kilometers off the northeast coast of Mindanao.¹⁵ Soundings to the westward of the Philippines have not yet located anything like such tremendous depths. We may then conceive of the Philippine Islands as being at the edge of the continental platform. This platform was subsequently raised above sea level, and complexly folded at the time of what is known as the "Miocene Revolution," which extended from New Hebrides through the Philippines northward to Japan; westward across Burma, India, Persia, and Egypt; northward to the Vienna basin; and westward even to the Pyrenees. Following this crumpling of the crust, a gradual tilting of the Philippine block

¹⁴ "Les tremblements de terre," Paris, 1906.

¹⁵ "Ann. Geog., No. 120, November, 1912.

toward the east seems to be going on at the present time. This is evident from the raised coral reefs on the western coast of northern Luzon, and western coast of Palawan, and raised deltas and beaches on the western coast of Zamboanga Peninsula with the existence of drowned river basins which we know of as certain on the eastern coast of Luzon, and at other points in the Archipelago about which we can conjecture although we have no definite information.

Von Richtofen,¹⁰ long ago, noticed a peculiarity of the Philippine Archipelago in connection with the Japanese, Riukiu, Kurile, and Aleutian chains of islands; namely, a series of arcs with their convex sides turned toward the Pacific. One of these arcs is well marked in the Philippines by the tectonic line passing through southeastern Luzon, Samar, and the Eastern Cordillera of Mindanao. Northern Luzon does not conform very well to this arc, but we may imagine that there has been a fault and offset at the narrow portion of the Island of Luzon, at the northern end of Tayabas Peninsula.

Besides this dominant curved line, and those parallel to it in the eastern part of the Archipelago, there are in the Philippines several other distinct tectonic lines. One of these is the Palawan line, another is the Sulu Archipelago line, others are the parallel lines passing northeast and southwest through Panay, Negros, and Cebu—all trending northeast and southwest. Masbate seems to be the "keystone" in the Philippine structure. The eastern prong of this island conforms closely with the outermost arc of the archipelago, while the western prong conforms with one of the northeast-southwest lines passing through eastern Panay.

Taking up the physiography of the Islands in detail: there is in the northern part, on the Island of Luzon, to the eastward, first a cluster of volcanoes containing Bulusan, Mayon, Isarog, and Iriga; then the narrow Albay Plain, west of this a belt of Tertiary sediments, and farther west a trough occupied by Ragay Gulf—the anticlinal, marked by Tayabas Peninsula and consisting of folded Tertiary sediments, lies west of this; then, the volcanic group consisting of Banahao, Cristobal, Arayat; west of these, the central plain of Luzon, partly a tuff plain and partly made up of alluvium; and farthest to the west the line of extinct volcanoes marked by the Zambales

¹⁰ Richtofen, Ferdinand v., "Geomorphologische Studien aus Ostasien," Sitzungsber. d. k. pr. Akad. d. Wiss. z. Berlin.

Cordillera. In northern Luzon a zonal arrangement exists, but is not so marked. Recent volcanoes are few, Kawa in Isabela Province being the only one we know in that section.

In the Visayas there is this same general zonal arrangement of formations, but the evidence of vulcanism is not so marked as in Luzon. The islands are marked by anticlines and the narrow straits by synclines.

This is likewise true of Mindanao. Along the eastern coast there are recent and Tertiary sediments flanking a core of igneous rocks on the immediate west, and dipping eastward toward the "fossa," or trough, just east of Mindanao; then the great Agusan trough; west of this an interrupted volcanic chain marked by such prominent points as Matutan and Apo; the great alluvial flat occupied by the Rio Grande de Mindanao; the regular zone of volcanic peaks marked by Malindang and the old craters south of Lake Lanao and those in the unexplored region south of the Rio Grande; farther west a belt of folded Tertiary sediments; then the synclinals marked by Sibuguey Bay; and last, the anticlinal marked by Zamboango Peninsula.

Cross folding, probably with faulting, has broken up the Philippine block in such a way as to produce numberless smaller islands in line with the main tectonic lines running through the larger islands.

Types of Mountains—Of the various kinds of mountains, such as folded, block, and volcanic mountains, the two dominant types in the Philippines are the first and the third. We suspect the block type in some places, where yet we have not sufficient data to prove it. It might seem at first sight that the majority of the mountains of the Philippines are volcanic, but these are merely superimposed upon the folded mountains or are located along other lines of weakness. While there are a few active volcanoes in the Philippines, most of the volcanoes are extinct or dormant, as shown by the many worn-down volcanic stocks, preserving in varying degrees their former outlines.¹⁷

The principal folded mountains are the Central Cordillera of

¹⁷ These various volcanoes have been taken up in other articles in more or less detail. The centers of volcanic activity at the present time are Taal Volcano in Batangas Province; Mt. Mayon in Albay Province, Luzon; Mt. Canlaon in Negros; and the Island of Camiguin, just north of Misamis, Mindanao. All of these volcanoes have been in eruption within the last ten years, and to them can be attributed many of the minor seismic disturbances to which the Archipelago has been subjected.

Luzon, the Eastern Cordillera which has its southern continuation in Tayabas Province, and the Cordilleras of Cebu, Leyte, eastern Mindanao, and various other parts of the islands.

Block mountains are rare in the Philippine Islands, but at Bambang, on the main line of the Manila and Dagupan railway in Luzon, there are some hills which are due to the Tertiary sediments being tilted up like blocks. From the railroad the tilted beds are seen presenting a bold escarpment to the east, undoubtedly due to a fault, but dipping gently to the southwest.

On the Island of Panay the secondary ranges, those flanking the Central Cordillera, are tilted blocks of Tertiary sediments. The strike of these secondary ranges conforms exactly to the strike of the sediments. Their eastern slopes correspond invariably to the dip of the formations. On the upstream side the slopes are precipitous where the upturned edges of the sandstone and the shale beds can be seen. Displacements along the bedding planes of these formations are frequent, and have undoubtedly given rise to many local earthquakes.

Kinds of rocks.—Before discussing the tectonic features of the islands it will be necessary to consider the distribution of the various classes of rocks. We have the following kinds to consider: (a) Deep-seated igneous, (b) extrusives, (c) intrusives, (d) Tertiary and older sediments, (e) metamorphic rocks, (f) recent alluvial and pyroclastic deposits.

(a) The deep-seated igneous rocks are diorite, gabbros, pyroxenite, peridotite, and syenite. These rocks have all been fully described.¹⁸ Their distribution is the principal thing of importance in this discussion. The deep-seated rocks are naturally not very widely distributed on the surface, and are found usually only in the canons of the central ranges. They are particularly abundant in northern Luzon, throughout the Central Cordillera; in the Island of Palawan; the Western Cordillera of Panay; the Central Cordilleras of Cebu and Leyte; the Eastern Cordillera of Mindanao; on the Island of Masbate; in fact, wherever the topography has sufficient relief so that the streams have been able to cut through the overlying, more recent formations.

(b) In all parts of the islands there is a large amount of extrusive material which forms a mantle over the deeper-lying formations. Naturally these are found around the volcanic areas; and these

¹⁸ Iddings, J. P., *Philippine Journal of Science*, Sec. A, 1910, 5, 155.

extrusives are very pronounced in the Zambales Range of southwestern Luzon, in various parts of the Central Cordillera lying above the old igneous and the Tertiary sediments. In the Central Cordillera of Luzon there exist great patches of andesite, marking probably early Tertiary volcanoes. In the Zambales Mountains there is a great development of andesite, marking probably a still later period of volcanic activity. On Mt. Arayat, which rises isolated out of the central plain of Luzon, basalt occurs; and around Taal volcano and on the Binangonan Peninsula there is a considerable amount of basalt. Extrusives are particularly well developed in the southeastern volcanic cluster of southeastern Luzon, comprising the well known peaks of Bulusan, Mayon, Isarog, etc. They are found overlying much of Masbate, particularly in the central portion; also in western Panay, a portion of Cebu (these may be intrusive), most of northern Negros, central Leyte, and notably in Mindanao, there being a broad belt of extrusives running north and south through the Apo and Matutan ranges. Also, there is a great patch of basaltic material around Lake Lanao, and a great volcanic mass, of which Mt. Malindang is the center. There is also a great development of these extrusives covering almost the entire islands of Basilan and Jolo, and the lesser islands of the Sulu Archipelago.

As yet, we do not know of any extrusives in Palawan, except in the north. The principal mountainous mass of Mindoro, Mt. Halcon, is largely andesitic.

There is one general conclusion which can be drawn from the distribution of the extrusives in the Philippine Islands: namely, that the entire recent volcanic activity consists, as far as we know, of basaltic materials, and that the older stocks are, without exception, andesitic.

(c) Small and large intrusions of diorite, granite, and basalt are innumerable throughout the islands. In the Central Cordillera of Luzon the intrusions seem to be generally diorite. They cut both the Tertiary sediments and the overlying extrusives. In the Province of Ambos Camarines, in southeastern Luzon, granitic intrusions cutting the diorite and possibly the sediments can be seen. In the Sulu Archipelago we have found a number of small basaltic intrusions cutting some of the recent sediments. Owing to the absence of an accurate base map of the Philippine Islands, and the fact that our work has been largely of a reconnaissance nature, these intrusions have not

been mapped in detail or with sufficient accuracy for us to state whether or not they follow any general system of jointing or earth lineaments.

(d) Flanking all the Cordilleras on both slopes there is a greater or less development of sandstones, shales, and limestones which have been bowed upward in the general Miocene uplift referred to above, with some minor crumpling at various points. The folding in the northern part of Luzon has apparently been a gradual and gentle uplift of the strata. In Tayabas Peninsula the strata have been so intensely compressed that schists are the result. These schists have been considered by some to be older than the Tertiary, but there seems to be no good reason for not referring them, in part at least, to the Tertiary. The central portion of Mindanao consists of gently folded sediments. The major axis of folding in the Philippines is in general north and south; along the outside arc of the islands, northwest and southeast; on the inside, northeast and southwest; but in central Mindanao in the Cotabato Valley the axis of folding is more nearly east and west.

(e) Metamorphic rocks occur more or less pronounced in various parts of the islands. In the Province of Ilocos Norte there is a considerable development of schist, and in Ambos Camarines there is a considerable development of schist and gneiss along the border of the granite intrusion referred to above. Schists have been found at one locality in the Central Cordillera of Cebu; at various points in Palawan; on the Zamboanga Peninsula alluded to above; in the Province of Bukidnon, Mindanao; on the Surigao Peninsula just east of the Gulf of Davao; at one point on the Tayabas Peninsula; and on the Caramoan Peninsula, southeastern Luzon. These schists appear to be for the most part metamorphosed sediments or igneous rocks.

(f) Recent alluvium from the mountains deposited upon coral shelves forms more or less development of coastal plain around all of the islands. The coastal plains are for the most part negligible, but some of the intermontane plains are very important. The northern three-quarters of the central plain of Luzon is largely alluvium. The Albay Plain is largely alluvium, as is the case in the great valleys of the Cagayan, Agusan, and Cotabato rivers. Also the central plain of Panay shows a very considerable accumulation of detrital material.

Around Manila we have, in addition, a great area of pyroclastic material which is cut through by the Pasig River. This is known from well logs and river sections to be at least 100 meters thick.

TYPES OF SEISMIC DISTURBANCES

Modern seismology, in rejecting every agent and force exterior to our planet as causes of earthquakes, reduces the classes of shocks to the following three types: volcanic, tectonic, and rockfall.

Many examples of these three types are to be found in the seismological records of the Philippine Weather Bureau, and a few of the more characteristic will be briefly mentioned.

To the *volcanic type* belong all those earthquakes that are intimately connected with volcanic eruptions caused by explosions or sudden outbursts of steam. These volcanic earthquakes, contrary to popular belief and to the ideas generally held for many centuries by scientists, are in reality of but slight importance and occur only in certain restricted districts.

The recent eruption of Taal Volcano, January 27 to February 8, 1911, offered a very typical series of these earthquakes. On the night of January 27th, severe earthquakes occurred on Luzon and in adjacent regions, while at the same time or very shortly afterwards it was noticed that the principal crater of the volcano increased in volcanic activity. This activity as well as the frequency and intensity of the shocks went on increasing during the 28th and 29th, until at approximately 2:26 on the morning of the 30th there took place the greatest and most destructive eruption recorded in the history of the volcano. After this paroxysm of eruptive activity the volcano returned to its normal state in a short time, although the earthquakes continued to be very frequent during the three following days, January 31st and February 1st and 2d, thus indicating that there was still an accumulation of energy in the interior of the volcano. During the eruptive period, namely, January 27th to February 7th, 995 shocks were recorded in the Manila Observatory, all of them between I and V of the Rossi-Forel scale. Some of the principal shocks were perceptible at a radius of from 120 to 200 kilometers. The meizoseismic area of the earthquakes was a prolonged zone which took in not only the volcano itself, but also the south-southwestern part of Laguna de Bay and the bordering territory as far as the sea, some 20 kilometers away (Plate V).

The decrease of perceptible intensity of the seismic action outside the epicentral area was, according to many comparisons made on the

spot, one degree of the Rossi-Forel scale for every 15 kilometers. The same result was also deduced from the fact that the maximum intensities of several of the earthquakes as felt in Manila, a distance of 63 kilometers, were from IV to V of the scale, while in the epicenter, judging from the effects in the ground and on buildings, they were from VIII to IX. These same earthquakes, which had an intensity VIII to IX in the epicenter and IV to V at a distance of 63 kilometers, were also felt at Taihoku (Formosa), some 1,000 kilometers away.

The reports of previous eruptions of Taal also make mention of numerous volcanic earthquakes, which no doubt possessed the same characteristics as those that occurred recently. A curious fact is noted in these reports: namely, that while in the recent eruption the meizoseismic area extended 20 kilometers to the south-southwest, in the previous eruptions it extended to the north-northeast for about 30 kilometers, as far as Laguna de Bay. From this it is easy to recognize the direction of the rift on which the volcano originated.

In 1871 a series of volcanic earthquakes occurred on the volcanic Island of Camiguin, north of Mindanao. These earthquakes culminated in the opening of a small crater whose activity lasted four or five years. They were first felt in February, and went on increasing in intensity and frequency until the morning of April 30th, when the volcano exploded and the earthquakes suddenly ceased. The greater number of these shocks was perceptible on the island only, although many were also heavily felt on the neighboring coasts of northern Mindanao and southern Bohol; while only four or five, whose intensities in the epicenter were between VII and X, were noticed at a distance of 250 kilometers.

The following table gives some idea of the number and intensity of the shocks preceding the eruption of Camiguin.

The *tectonic type* of earthquakes is caused by the sudden relief of strains, due to contractions and foldings in the crust of the earth; when these pass the limit of equilibrium and the modulus of elasticity of the crust, they give rise to rents and fractures and other sudden movements of more or less severity, depending on the degree of the accumulated strain. This type comprehends the greater number of earthquakes felt in all parts of the world, and in particular all those of greater intensity and extent. To it belong practically all the great

REGISTERED AT MANILA

DATE	EARTHQUAKES	REMARKS
1871		
Feb. 16.....	Two slight earthquakes.....	
" 17.....	Frequent shocks during day and night.....	
" 18.....	" " " ".....	One of intensity VIII.
" 19.....	" " " ".....	One of intensity VII.
" 20.....	" " " ".....	
" 21.....	" " " ".....	One of intensity IX.
" 22.....	" " " ".....	One of intensity VIII.
" 23-28..	" " " ".....	
Mar. 1-3....	" " " ".....	
" 4.....	" " " ".....	One of intensity VI.
" 5-7....	Less frequent, not more than 10 per day.....	
" 8.....	" " " ".....	Two of intensity VI.
" 9.....	" " " ".....	
" 10.....	" " " ".....	Two of intensity VI.
" 11-13...	" " " ".....	
" 14-17...	Less frequent, 4 or 5 per day.....	
" 18-19...	More frequent and violent than during preceding days.....	
" 20-31...	Less frequent, not exceeding 6 per day.....	
Apr. 1-29...	Frequent during the entire month; number never less than 6-10 per day.....	
" 30.....	At 7 a.m., with a terrific detonation and emitting a cloud of vapor, rocks, and ashes, a volcano burst on the north-northeastern end of the island, only a few meters from the shore. After this explosion, semifluid lava continued to rise quietly for about three years, building up a cone approximately 400 meters high. The ashes of the first explosion were carried to distances of 200 kilometers. Within a radius of 2 to 3 kilometers from the new crater the destruction was complete. The earthquakes ceased almost completely a few days after the eruption. There was no loss of life as the people of Catarman, the town nearest to the volcano, and the only one destroyed by it, had deserted their homes long before, some having left for other islands as early as the end of February.	

Philippine earthquakes enumerated by Fr. Saderra Maso,¹⁹ which occur in eastern Mindanao, in the Valley of the Agusan, and on the Pacific coast, regions which appear to be closely related to the great submarine trough, "the Philippine deep" of 9,780 meters, already re-

¹⁹"Catalogue of violent and destructive earthquakes in the Philippines," *Bulletin Philippine Islands Weather Bureau*, 1910.

ferred to. Further on we shall discuss some of the tectonic earthquakes of greater importance.

The *rockfall type* embraces the earthquakes of small extent, which, having their focus or seat or origin at a slight depth, are brought about by the fall of rock in caves and underground passages, and in certain cases by the settling of superficial rock-masses displaced by tectonic seismic motions. It appears that this is the predominant type of shocks felt in several non-volcanic regions of the Philippines; but earthquakes of this type are very often extremely difficult to recognize, on account of the distance between the seismic stations, and the large extent of the uninhabited mountainous and forest districts in which they occur, so that it is impossible to fix the limits of the area where many of the earthquakes are perceptible. We consider as unimportant examples of this class of earthquake those of 1881 in Nueva Vizcaya. From January to October of that year there was a continuous series of earthquakes, the maximum of intensity and frequency occurring in September. To get an idea of this seismic period, the well known catalogue of the missionary Xavert should be consulted. This catalogue takes in sixty-three days between January and October, and contains the record of 196 earthquakes, with the times at which they occurred. Phrases such as "almost continuous," "many more," "the whole day," "the whole night" appear twenty-five times in the list, thus indicating that the smaller earthquakes were not counted.

Abella, who examined the effects of these earthquakes in the field, found that the meizoseismic area was of very small extent, and that its center coincided with the town of Bambang. The great majority of the shocks were only perceptible within an area of sixty kilometers, so that only five of intensity VII to IX exerted any influence beyond the province. Much of the data supplied by Abella fully confirms his statement, which is further strengthened by an examination of the records of the hourly observations of the Bertelli microseismoscope, or tromometer, made in the Manila Observatory.

With the catalogue of Xavert before us, these observations have been examined again, and we have not been able to find any movement which could coincide with the Nueva Vizcaya earthquakes, other than the ones corresponding to the larger shocks mentioned above, and three or four other doubtful ones. The experience of seventeen years shows us that this tromometer, still in use at the Observatory, indicates perfectly all earthquakes of any great extent, and of intensity

III or greater, whose epicenter lies within a radius of two hundred kilometers from Manila.

Abella deduced from these facts that the seat of origin of the earthquakes must be very superficial and of small extent; and hence the conclusion, that there was little likelihood of any greater ones happening in the future, was fully verified. Such earthquakes could not in any way be classed as tectonic, and hence the author attributed them to volcanic influences, suggesting that the subterranean forces, which at that time had given greater activity to Mayon Volcano, might possibly have extended toward the northwest and affected the Province of Nueva Vizcaya, some four hundred kilometers from Mayon. After the examination of Abella's report, it seems evident that the earthquakes of Nueva Vizcaya belong to the rockfall type; and this opinion is strengthened by a consideration of the topography of the province. The whole province is an elevated mountainous region of the nature of a plateau, separated from the plains of Luzon to the south by a line of steep cliffs, while on the west it is bounded by a series of peaks whose precipitous western slopes rise abruptly from the deep cañon of the Agno river.

Besides the earthquakes of Nueva Vizcaya, many of those that take place in the Mountain Province, which comprises the former districts of Benguet, Bontoc and Lepanto, possibly are of the same character. In many parts of this region, particularly in the western part, where coraliferous limestone predominates, recent fractures and subsidences are to be met with at every step. The same might be said of other parts of the Archipelago, having a similar geological structure.

DISTRIBUTION OF SEISMIC DISTURBANCES

In the Philippines, as in all other seismic regions of the globe, most earthquakes originate along determined lines which constitute special features of the topography of the Archipelago.

If we add to the "Catalogue of violent and destructive earthquakes in the Philippines, 1599-1909," cited above, the earthquakes which have occurred since that time, we have the distribution of tectonic epicenters²⁰ as given on the map (Plate V).

The region which has suffered most from violent earthquakes

²⁰ The word "epicenter" is used in the broad sense, as the region where important earthquakes originate.

during the past fifty years is without doubt eastern Mindanao, and particularly the Agusan Valley. We have no seismic data of this region from a period more remote than 1889, but this is doubtless owing to the undeveloped state of that part of the Archipelago, and to the consequent lack of communication with the outside world. The great deep-sea trough which exists along the east coast of this part of the island indicates that many earthquakes must have occurred there since it first began to form. The same may be said of the coasts of the Island of Samar, which also are exposed to the influence of the same "deep," and hence that they also are as unstable as the eastern coast of Mindanao. The principal epicenter of Samar is near the northeast coast.

In the Island of Mindanao there exist the following seismic regions: The Gulf of Davao and the districts of Cotabato between Apo Volcano and Illana Bay; the coast along Illana Bay and the district of Lanao; the extreme western part of the island near Zamboanga. The Island of Basilan and the Archipelago of Jolo are also in a region of great seismicity, although the epicenters seem to lie in the neighboring seas. The district of Dapitan in the northwest is affected by a submarine epicenter situated between Dapitan and southern Negros. All the central part of northern Mindanao comprised within the district of Misamis appears to be a region of much greater stability, but the neighboring Island of Camiguin has suffered much at different times from volcanic earthquakes. The Viscayan Islands, in addition to what has already been mentioned of Samar, have two regions of great seismicity, Panay and Leyte. An epicenter lies in the Iloilo Straits between Panay and Negros, while within the Island of Panay at a distance of about thirty kilometers from the southeast coast there is another more important one where originate very violent earthquakes, but apparently of the rockfall type. In Leyte there are two volcanic epicenters, one in the southeast and the other in the north and northeast; and there is probably a rockfall epicenter to the west, close to the Camotes Islands.

The Islands of Cebu and Bohol, and perhaps also Oriental Negros, may be considered as stable. However, Oriental Negros was very probably in the past the scene of many volcanic earthquakes, though the data we possess are very deficient. Volcanic formations more recent than the Pliocene do not occur in Cebu.

The principal seismic regions of southeastern Luzon and adjacent region are those of Camarines, Albay, and Masbate, with three principal and well defined epicenters: the first along the central depression

of Ambos Camarines, the second to the north of San Bernardino Strait, and the third in the Island of Masbate, or near its northern and southern coasts. Between Sorsogon Bay and the Gulf of Albay there is also an epicenter of small extent and intensity.

The southern part of Luzon constitutes the second seismic region of greater importance in the Archipelago. Four epicenters may be distinguished in it: one in the east, near the coast, which appears to stretch from the north of the Bay of Lamon to the south in the sea between Mindoro and Marinduque; a second between Mindoro and Luzon; a third in the China Sea along the coast of Cavite and Zambales; and the fourth, which may be called the Manila epicenter, is situated in the Eastern Cordillera and its spurs, between Laguna de Bay and the Gulf of Baler. The volcanic epicenters of Taal and other volcanoes are not reckoned.

Northern Luzon from parallel 16° northward contains four extensive seismic regions: That of Pangasinan, whose long axis appears to cross the island approximately from east to west, from the Bay of Casiguran to the Lingayen Gulf, following the limit of the great central plain of the island; the Nueva Vizcaya epicenter may be considered as belonging to this central seismic region. The second region is comprised of the various epicenters of Ilocos Sur and Norte, some of them in the sea close to the coast, others probably at the extreme east of the plain or costal belt which borders these provinces. The third region, which is an important one, is situated along the central mountain chain of the Mountain Province, and extends as far as the Babuyan Islands. Within the confines of the extensive Cagayan Valley there are very important tectonic lines, but they have not, since 1645, given rise to any very great earthquake. However, there are frequent earthquakes of slight extent and intensity, those occurring in the north being probably of volcanic origin, while those in the south are due to epicenters whose influence seems to decrease.

In the extreme north of the Archipelago and outside the limits of Luzon there are at least two epicenters close to the meridian 122° east: one stretching from the volcanic Island of Camiguin to the northeast coast of Luzon, and the other not far from the Batanes Islands.

In Luzon, therefore, no province is free from the effects of earthquakes; for although it is true that in some of them, such as Tarlac, Union, Isabela, Cavite, and Pampanga, no epicenter seems to exist,

still they are affected by the movements which originate in other provinces.

Seismotectonic lines.—The map, Plate V, gives the location of the principal seismic areas (red ellipses) of the Islands (the stars indicating the principal epicenters in these areas), and the general direction of certain principal mountain chains.

Each figure includes one or more epicenters and shows the general shape and extent of the meizoseismic areas, corresponding to the greatest earthquakes which have occurred within the region limited by the same. The figures 3, 5, 7, 8, 9, 10, and 23 bear a heavy line, to indicate that the earthquakes originating near the same place have been too many to be specified. Twenty-five different areas are recorded, and of these five, maps 12, 13, 15, 17, and 18, are undoubtedly due in large part to rockfall and volcanic activity; the other twenty, in our opinion, being due to tectonic causes. This is probably quite contrary to the general belief regarding earthquakes in the Philippines. The tectonic areas are 1 to 11, 14, 16, and 19 to 26. *The areas of greatest seismicity are 2, 3, 4, and 21, where at the present time there is no known volcanic activity, and where probably there has been none since the end of the Tertiary period.*

Following the methods of other students of seismology, we have connected the various epicenters shown on the map by lines, and have also added a few more of the latter where no epicenters are indicated. There is a remarkable coincidence between the lines and the principal lineaments in the Philippines. These various lines are denoted *A-A*, *B-B*, etc., on Plate V, so that they can be easily referred to.

Line *A-A*, which is drawn through many epicenters, passes through the northwest corner of the Province of Ilocos Norte, follows approximately the coast west of the city of Vigan, and then cuts across the northwest portion of Pangasinan Peninsula. It is impossible definitely to state whether this line marks a fault line which lies along the coast, or is due to a contact between the recent sediments and the older rocks which here lie close to the coast; but we are of the opinion, from geological studies in the Province of Ilocos Norte, that the latter is true.

There is a very small development of coastal plain in this region, and also rocks of doubtful age which may possibly belong to the Jurassic, against which these very recent sediments abut. There is also a considerable development of raised beaches and raised coral reefs

along this coast, making it plain that elevation has taken place along this line in recent times. Whether this elevation has been accompanied by differential movement, we are unable to say.

There are no evidences of recent volcanic activity in any part of the region, but granites, schists, and some very old andesite are present.

Line *B-B* connects epicenters of northern and southern Luzon, cuts through Dalupiri, the westernmost of the Babuyan Islands, then very closely follows the Central Cordillera southward through the Agno Valley, thence to the eastward of the Zambales Range, and on through the Island of Mindoro, where it cuts the latter west of the great volcanic stock of which Mt. Halcon is the principal peak. There is no information with regard to the rocks on Dalupiri. However, the rocks of the Central Cordillera in Luzon have a core of tectonic rock, chiefly diorite, flanked by Tertiary sediments which have been arched upward, and in various points along the crest of this arch extrusive rocks can be found in abundance. No volcanic activity now manifests itself in that region, but it is a region of hot and of salt springs. It is a line along which there was considerable extrusion of igneous rocks in the past, but there is no evidence of this now; therefore, seismic disturbances which take place along this line at the present time are due to displacement along a line of weakness rather than to any volcanic activity. *It is significant that all of these points where either past or present volcanic activity is manifested should be found to lie along more or less definite, and in many cases, straight lines.*

Line *C-C* is the next prominent line, which runs at right angles to the *B* line, and lies either on, or very close to, four epicenters. At the upper end of the central plain of Luzon the mountains rise rather abruptly, and present a front which has a general east and west direction. It is very possible that this line represents a fault line, where the central plain represents the downthrow side. That area has not been studied in detail, but it appears as if there is a definite break along that line. In a more arid region one would expect to find definite escarpments facing to the southward; but in a region of high rainfall, like the Philippine Islands, naturally these escarpments would very soon be obliterated, so that their existence can only be inferred.²¹

Line *D-D* is a very prominent line which runs along the Archipelago close to the 122d meridian. It connects the epicenters of the

²¹ Hermann, Raf., *Philippine Journal of Science*, Sec. A, 1911, 6, 331.

Batanes Islands, Cagayan Valley, Casiguran Bay, east of southern Luzon and Mindoro, and west of Mindanao. The northernmost part of the line, outside of Luzon, follows very closely the Batanes and Babuyan volcanic chain, studied by H. G. Ferguson²² and represented by the cones Yami, Mabudis, Inem, Iraya, Balintang Rocks, Babuyan Claro, Camiguing, and Didicas. Within Luzon it passes not far west of the Caua Volcano, southward along the structural Cagayan Valley, following the trend of the Eastern Cordillera until this turns toward the southwest, or rather when it seems to be interrupted by the gap forming Casiguran and Baler Bays. From the latter bay it follows the eastern coast of Luzon, and passes to the Mindoro Sea through the volcanic region of Tayabas Province. Farther on toward the south it passes fairly close to Tablas Island, which is oriented in this direction, thence to the west coast of Panay, ending finally between Basilan and Jolo. The general topographic features suggest that this is a very characteristic tectonic or structural line, though definite geological reconnaissances are wanting to confirm such an hypothesis.

Line *E-E* passes through many epicenters. It lies just west of the epicenter near Bayombong, Nueva Vizcaya, and passes through some near the east coast of Luzon and Lamon Bay and at the southeast corner of Leyte, and connects with the epicenters located around the northern point of Surigao Peninsula. This line is seen to conform to the Central Cordillera of Leyte, to the coast range of Masbate, the synclinal marked by Ragay Gulf, but we are not certain that it conforms to any particular lineament in Luzon, as it passes through country about which there is little geological information. There are closely folded sediments whose strike is northwest-southeast in the eastern portion of Masbate, and Adams²³ has visited the Island of Leyte and mapped the cordillera, showing its axis to be approximately along this line.

Line *H-H*, which has been called "The Taal Volcano line,"²⁴ starts from the northwestern part of Mindoro and in a nearly northeast direction crosses Taal Volcano, the western portion of Laguna de Bay, extending into the Eastern Cordillera, east of Manila, and

²² Manuscript report.

²³ *Philippine Journal of Science*, Sec. A, 1909, 4, 339.

²⁴ Saderra y Masó, Fr., *Bulletin Philippine Islands Weather Bureau*, 1911, 4.

tion of the "Philippine trough"; along which are located some epicenters affecting Cantanduanes, Albay, and northern Samar.

Line *O-O* begins close to the epicenter at the southern point of Samar, continues south to the Island of Dinagat, through the epicenter at the northern point of Surigao Peninsula, then approximately conforms to the Matutan Range, through the epicenter near Mt. Apo, and finally passes through the Island of Sarangani. We do not know the composition of the rocks of the central part of the Island of Dinagat, but on Surigao Peninsula crystalline schists flanked by Tertiary and recent sediments have been noted. In the neighborhood of Lake Mainit the rocks are volcanic, although just to the east of this body of water is a belt of metamorphics. In the Matutan Range the rocks are largely extrusives of more or less recent date.

Line *P-P* passes through three epicenters and along very important structural lines in the Archipelago. Beginning at the north, it passes between the Islands of Cantanduanes and Luzon, through Batan Island, south through an epicenter located near the southern end of Leyte. From here it extends through one in Butuan Bay, thence traversing very closely the structural line of the Agusan Valley in Mindanao, and finally emerges from Mindanao near the town of Mati. Very little is known about the geology of the parts of the Archipelago traversed by this line. In the Island of Batan the rocks are largely sedimentary; however, their strikes do not coincide with this line at all.

The Agusan Valley in Mindanao is very clearly a structural valley. What the condition of the rocks is with depth, we do not know, as the alluvial filling in the Agusan trough conceals everything. This line is one of the most important in the Archipelago, and has been described in previous articles.²⁸ In the first of these Fr. Saderra Masó says:

"We call this line the line of the Agusan River Valley, because *the portion of it which lies within the said valley has been the seat of the greatest number of violent earthquakes which have occurred during the last fifty years.* The first seismic district of importance of this line comprises the large gulf of Davao, 120 kilometers long and

²⁸ Saderra y Maso, Fr., *Bulletin Philippine Islands Weather Bureau*, August, 1910; July, 1911.

to the west of the axis of the Zamboanga Peninsula, as it is believed that some earthquakes have originated from displacements along the west coast of this peninsula.

Line *L-L* passes through an epicenter at the southern point of the Island of Samar and another near the end of the southeastern prong of Leyte, through the Island of Camiguin on which is located an active volcano, and then follows the trend of Misamis Bay, in Mindanao, and finally passes close to an epicenter situated in the middle of the sea between Cotabato and Zamboanga. Formations at the lower end of Samar and Leyte are but little known; but there is a dormant volcano on the Island of Camiguin, and where the line crosses Mindanao there is more or less basalt. Misamis Bay probably marks some sort of a rift in the formations.

Line *M-M* passes through many epicenters in the Island of Mindanao. It intersects the *L* line at a point east of Dumanquilas Bay, passes through an epicenter west of Pollok, then follows very closely the trend of the Cotabato River to the point where the river turns northward, and thence through an epicenter located in the sea east of the southeastern point of Mindanao. Note the agreement between this line and the lower course of the Cotabato River—which is probably more than a coincidence.

Line *N-N* connects important epicenters in Camarines, Nueva Vizcaya, Samar, Leyte, and the northeast coast of Mindanao. It passes through the narrow Strait of San Juanico, separating Samar from Leyte, and along the Camarines Valley northwestward it strikes the eastern coast of Luzon, south of Casiguran Bay. In the Albay Valley it follows the contact line of the northern volcanic cluster, along which the most violent earthquakes of the Camarines seem to originate, probably due to differential movements between the sedimentaries and the volcanic area, or possibly in the sedimentaries alone. Farther in the interior of Luzon this line would pass very close to the Nueva Vizcaya epicenter, but this epicenter is considered as rockfall.

Line *N'-N'* is a secondary one which would pass through the Sorsogon and north Samar epicenters. This line nearly coincides with the contact between the sedimentaries and extrusives, west of Sorsogon; eastward it follows the tuffs and agglomerates of the lowland extending from Sorsogon to Gubat. In the St. Bernardino Straits and in the north of Samar it nearly conforms to an indenta-

490 kilometers from north to south, that is, from the southern coast of Batangas and Tayabas to the northern part of Cagayan. On the western coast it seems to have been of less intensity; at least the chronicles of the time are silent about its effects in these parts, while they deal very much with the destruction caused in Manila, and neighboring provinces of the south, east, and north, and the tremendous effects produced as far north as Lallo, in the Cagayan Valley, and in the eastern part of the Central Cordillera, that is, in the Mountain Province. That such an earthquake was due to tectonic movements, there cannot be the slightest doubt; furthermore, it is very certain that its origin was along a north and south line, and that this line was within the Island of Luzon and not beyond its eastern periphery; it may be reasonably supposed that it was along the seismotectonic line *D-D*. The question arises whether the dislocations which then occurred along that line or fault were of such proportions as to be responsible for the many singular topographic features existing now along it in the Provinces of Nueva Ecija, Nueva Vizcaya, and Isabela. Moreover, as in that memorable earthquake the city of Manila seems to have been very close to its origin, our opinion is that some dislocations occurred at the same time along the fracture represented by the line *H-H*. Similar occurrences of lines crossing each other are frequent in severe earthquakes. For example, the earthquake which occurred in 1870, having its epicenter in the northwestern portion of Luzon, apparently was of tectonic origin, and might be explained as due to a displacement along the line *A-A*.

The great number which occurred in 1871 were of volcanic origin, having as their epicenter the Island of Camiguin. The destructive area included the Island of Camiguin, the Island of Bohol, and that part of Mindanao known as Misamis; also the southwest corner of Leyte.

Earthquakes of July 11 (3) and of November 5, 1871 (17), are both clearly of tectonic origin. The destructive area in the case of the first comprises the Central Cordillera of Luzon; and that of the second is located along line *E-E* or, perhaps, line *P-P*.

Earthquake of December 29, 1872 (7).—The destructive area comprises roughly that portion of Luzon adjacent to line *F-F*, but it is possible that these disturbances originated from the Taal Volcano fracture. No eruption of Taal Volcano is recorded for this year.

Earthquakes of August 25 (22, 23) and October 16, 1874 (8, 9).—In the former the destructive area comprises the Zamboanga Peninsula, and is clearly tectonic, probably due to dislocations along the line *I-I*. In the second, the destructive area comprises the region east of Manila Bay, more or less elongated north and south, and possibly has some connection with the line *D-D*. Taal Volcano was probably not the cause of this disturbance.

Earthquakes of May 1 (7, 8) and of July 5, 1877 (10, 11).—The former was felt over most of southwestern Luzon, probably emanated from Taal Volcano, and probably was due to movements propagated along the line *G-G*, which follows the western limit of the central plain of Luzon. The latter may have been of volcanic origin, as the whole southeastern volcanic region is comprised in the destructive area; or it may have had its origin in some movement along the line marking the Philippine "deep" (*X-X*).

Earthquakes of August 13, 1878 (7, 8), and of July 1, 1879 (17).—The former seems to have had its epicentral area located near Manila Bay, resulting from disturbances along the line *G-G* mentioned in the last paragraph. The latter had its destructive area in northeastern Mindanao and Surigao Peninsula; was possibly due to the Agusan line, but more likely due to displacements along the line *E-E*.

Earthquakes of July 14 and 25, 1880 (5, 6, 8, 9).—The destructive area shown on this chart indicates that the disturbances originated somewhere in the Eastern Cordillera of Luzon. Two originated along line *H-H*, and the third in the eastern part of Laguna Province, line *D-D*.

The earthquakes of July 25, 1880 (5, 8, 9), show that the destructive area conforms pretty closely to that shown in Chart VII, *La Seismologia en Filipinas*. These should both be classed as tectonic.

Earthquakes of May 15 (4, 5, 6, 8) and of July 11, 1881 (15).—In the case of the former, the destructive area is confined to the Eastern Cordillera in north-central Luzon, and is clearly of tectonic origin. That of the latter had its center on the Island of Guimaras, just south of Panay. This is clearly of tectonic origin, and it was probably due to displacements along the contact between the Tertiary sediments of the western half of the Island and the igneous rocks of the eastern half.

The earthquake of July 16 in Ilocos Norte Province, Luzon (2), was undoubtedly due to disturbances along the line *A-A*.

Earthquakes of September 10, 1881 (5).—The area of destruction during these earthquakes was very local, being in the southern part of Nueva Vizcaya, and may be attributed to purely local causes, possibly rockfall.

The earthquake of September 30, 1881 (4, 5), again centers in Nueva Vizcaya, and was probably of the same origin as the previous one.

Earthquake of April 30, 1882 (7, 8).—The destructive area was very local and was centered just north of Manila Bay, but more to the west near the contact between the material of the valley floor and the volcanic rocks of the Zambales Mountains; hence there seems to be some reason for conjecturing that it is due to tectonic causes. On September 12 a very similar earthquake occurred in the same region.

Earthquakes of July 25 (7, 8) and 28 (2), 1882.—During the former the epicentral area is situated between Taal Volcano and the China Sea, and hence may be of volcanic origin. That of July 28 is located along the Cordillera of Luzon in the northern part, and hence may be called tectonic.

The earthquake of September 11, 1882 (7), has its focus somewhere near Taal Volcano.

Two earthquakes on September 17 (10) and 21 (2, 3), 1882.—In the case of the former the destructive area is centered about the southeastern volcanic cluster in Luzon. The latter has its epicenter in north-central Luzon, but the longitudinal axis of the destructive area runs slightly north of east. We do not know of any prominent structural line in that region running in that direction. The course of the Abra River where it makes a sharp right-angle bend to the west in the latitude of Vigan, is suggestive of some prominent earth lineament. On September 6, 1862, October 9, 1901, and May 25, 1907, very similar earthquakes occurred in the same region, having their main line of propagation in nearly the same direction.

On October 10, 1882, there was an earthquake, the destructive area of which centers about San Miguel Bay in southeastern Luzon (10). Very little is known about the formation on the Caramuan Peninsula, so we are unable to give any theory for the disturbances here.

Two earthquakes of February 10 (3, 4) and of July 14, 1883 (10).—The former originated in the Province of Nueva Vizcaya, and probably was due to causes already mentioned. In the latter, the earthquake clearly originated from volcanic disturbances, as the destructive area comprises the southeastern volcanic region of Luzon.

Earthquake of July 27, 1883 (7, 8), is clearly volcanic, or at least related to the fracture passing through Taal, which is included in the destructive area.

Earthquakes of January 10 (10) and March 22, 1884 (5).—Both of these were very likely of tectonic origin; one had its epicenter in the northwestern portion of Pangasinan Province, where there is no sign of recent vulcanism. This probably is due to displacements along the line *G-G*. The second one had its epicenter near the southeastern volcanic region, but on the west side of the peninsula, where there is a slight uplift of Tertiary sediments, which may indicate this to be due to tectonic causes. Lately—in 1907—there occurred two destructive earthquakes in the same region, probably due to the same causes.

Earthquake of April 20, 1884 (7).—This was not destructive, but, according to the distribution of the effects of the earthquake, it probably was of tectonic origin, and can be attributed to displacements along line *G-G*.

Earthquake of October 29, 1884, had two destructive areas (6, 8, 9) more or less separated, the epicenter of one being just north of Laguna de Bay, and the other just north of the southeastern volcanic cluster (10). There is no sign of a volcano at present north of Laguna de Bay, but it is probable that the line *H-H* runs through this region.

Earthquakes of December 17 and 24, 1884 (5, 13), are clearly of tectonic origin. In the former the displacement undoubtedly took place along the line *C-C*, and that of the latter was probably due to movement along the line which runs from northwest to southeast, through the straits between Leyte and Samar, which is indicated by the line *N-N*.

Only one earthquake (2, 3) is shown on this chart, and that seems clearly to have originated along line *A-A*.

Earthquakes of July 23 and 24, 1885 (5, 6).—The first seems to have its epicenters northwest of Dapitan Peninsula. In 1897 an-

other destructive earthquake occurred under the sea in the same region, due to the same origin. It is very likely that this is of inter-tectonic origin, due to line *I-I*. There is no record of any volcanic demonstration emanating from the Dapitan Peninsula. It seems very clear from the great lineal extent of the destructive area of this earthquake north and south, that the line *I-I* is responsible; hence this would be called tectonic. The earthquake of the 24th of the same month seems to be similar to that of December 17, 1884.

Earthquake of November 16, 1885 (7, 8).—This is clearly of volcanic origin, as it seems to have been most generally felt in the southwest volcanic region of Luzon.

Earthquake of November 19, 1885 (5), is similar to that of July 24, 1885, and is also tectonic.

Earthquakes of April 10 (15) and August 2, 1886 (7).—The first one is undoubtedly tectonic, and is connected with line *J-J*. The second may be in part volcanic, but on account of its extension to the northwest we believe that it can be referred to the tectonic line *G-G*.

Earthquakes of February 1 (3) and 2, 1887 (14).—The former seems to have been localized in north-central Luzon, and may or may not be tectonic. It is possible that this disturbance was due to rock-fall. The latter earthquake seems to have affected the whole Island of Panay, and was probably due to rockfall, because a recent examination of this island has shown that landslides of considerable magnitude are of frequent occurrence on this island. In these two regions violent earthquakes of like character, and probably of the same origin, occurred in 1902 and 1904.

Earthquake of March 24, 1887 (10), was unquestionably of volcanic origin, due to disturbances in the southeastern volcanic cluster of Luzon. The two earthquakes here shown of June 19 (6, 8) and October 1, 1887 (10, 11, 12), respectively, were only light ones. The second one emanated from the same volcanic region as the earthquake just mentioned, but that of June 19 was undoubtedly of tectonic origin in the Eastern Cordillera.

Earthquakes of June 27 (20, 21), May 3 (2, 3), and August 19 (4), 1888.—The first is undoubtedly tectonic, as we know of no volcanoes anywhere in that portion of Mindanao; but we also do not know enough about the geology of that portion to say with any cer-

tainty that there is a tectonic line running at an angle to the main Agusan line. The reader is referred to an article by Fr. Saderra Maso³⁰ on this subject.

On Plate VIII of that paper the author has indicated the several epicentric areas near the "Philippine Deep." Most of these areas are elliptical, with their long axes extending north and south or northwest and southeast, but one of these has its long axis extending slightly north of east to slightly south of west. The second seems to have had its center in the Cordillera of northern Luzon. The third is a clear case of movement along line *D-D*, or the Cagayan line.

Earthquakes of January 1 (17), February 5 (22, 23, 25), May 26 (7, 8), and of October 6, 1889 (17, 20, 21).—The first is clearly due to movements along line *E-E*, and the second along line *M-M*. The third without question is due to the lines or fractures *H-H* and *F-F*. The fourth affected the whole Agusan Valley region, and the eastern coast can be attributed to the "Agusan line," or rather to the Pacific structural "deep."

In addition to the above list of earthquakes in the article "La Seismologia en Filipinas," we desire to add the following important earthquakes:

Earthquake of 1892, Pangasinan, Benguet, and La Union Provinces (5).—The tectonic nature of this earthquake seems to beyond doubt, since it occurred in a region where no recent volcanic formations are to be found. The northern part of its epicentral area comprises the uplands of Baguio, where the tremendous upheavals which occurred in recent geologic periods are clearly evident. Almost in the center of the epicentral area rises Santo Tomás, an andesite block mountain due in part to faulting; while in the southern part lies the alluvium of the Pangasinan plains. It seems highly probable that the cause of this earthquake can be found in some important dislocation which occurred near the Santo Tomás mountain mass. This epicenter belongs to line *C-C*.

The earthquake of 1893, Agusan Valley, Mindanao (20), is unquestionably the greatest which has occurred in this region during the last three centuries. The permanent sinking of part of the floor of the valley, and the faulting on the divide between the headwaters of the

³⁰ "Seismic centers of Samar, Leyte and Eastern Mindanao, *Bulletin Philippine Islands Weather Bureau*, August, 1910.

Agusan Valley and the Gulf of Davao, suggest a folding movement of the Eastern Cordillera as a whole, or a slip toward the east, in connection with the changes which possibly occurred in the deep trough running along the east coast. Therefore this earthquake must be classified as most typically tectonic, as it occurred along a most definite structural line.

Earthquakes of 1897.—The natural and fearful happenings of this year bring to mind the somewhat fabulous occurrences of 1641, when earthquakes in Luzon occurred at the same time as eruptions in Mindanao, Jolo, and Sanguir. During this year destructive tectonic earthquakes were felt in northern Luzon (2), northern Samar (11), Masbate (12), eastern and western Mindanao (19, 22, 23, 24), while as a climax Mayon Volcano had one of its worst eruptions. The most typical and important of these earthquakes was the one occurring in western Mindanao. Its origin or epicentral area seems to have been under the sea, west of Zamboanga Peninsula, where two very important lines, *L-L* and *D-D*, intersect. It must be considered as one of the most memorable of Philippine earthquakes, on account of the most extraordinary seismic wave ever noticed in the Archipelago. Furthermore, it seems to have been connected with the rising of some temporary islands near the northwest and northeast coasts of Borneo.

Earthquake of 1902, Illana Bay, Mindanao (23), shook heavily the districts of Cotabato and Lanao; its epicentral area comprised part of the bay, where the telegraphic cables were broken and buried under mud, the eastern coast and plain of Cotabato, and the northern coast of the uplands of Lanao District as far as the lake. In this last region there had been great volcanic activity during the Tertiary period, as is shown by the basalt and lava flows which cover it, and some old volcanic cones rising toward the south and east; but, during the historic period, only one doubtful eruption is reported. Consequently, considering the wide extension of this earthquake and its effects upon land and the bottom of the sea, it should be classified as tectonic, and connected with line *M-M*.

PRACTICAL CONSIDERATIONS

1. The fact of the instability of the earth's crust has been proved time and again, both by tremendous catastrophes and by laboratory experiments. It has been demonstrated that many of these devastating

earth movements take place along definite lines of weakness in the crust. The location and extent of these lines can usually be fairly accurately determined by a geological examination.

2. The points of intersection of such lines are dangerous, as can be shown by an examination of the Province of Calabria in Italy.³¹

3. Volcanoes are only incidental phenomena, and are results rather than causes. They are usually found to be lined up along some rift line.

4. Points of danger in the Archipelago are:

a. Along the Taal rift line from the town of Lemery to Los Baños on Laguna de Bay, and possibly farther to the northeast.

b. All "made" land. The California Earthquake Commission (1908) reported that the intensity of the shocks and the destruction were greatest and the amplitude of the waves longest in the "made" grounds.³²

c. The Agusan Valley, Mindanao.

d. The Straits of San Juanico.

e. The district northeast of Manila near the east coast and northwest of the Island of Polillo. Three prominent lines intersect in two places close together in this region.

f. That part of Batangas Peninsula which ends in Cape Santiago.

5. Types of structures best suited to Philippine conditions:

a. Bamboo houses. These are so built that they are all tied together and behave like a basket. They are strong, elastic, and light, and act like a single piece of material.

b. "Strong material," a term locally used to distinguish wooden, well-nailed houses from bamboo structures. Floor joists well anchored.

c. Sand-lime brick tied to steel—frame—should be cheaper than concrete, and in case of warping walls can be removed easily and new steel put in.

d. Reinforced concrete, perfectly safe if properly made; but expensive, and apt to receive permanent warping and fissuring³³ from the twisting motion of some earthquakes.

³¹ Hobbs, W. H., "Some Principles of Seismic Geology," *Beitragen zur Geophysik*, 8, Heft 2, 224.

³² "Report of California Earthquake Commission," Washington, 1910.

³³ In the severe Sorsogon earthquake, November, 1912, a new school-house of reinforced concrete and concrete blocks was considerably damaged in both portions, the reinforced concrete portico sustaining considerable fissuring.

c. Ordinary brick walls with roof of unanchored tiles make one of the worst possible types of construction, as demonstrated at Messina.

6. The necessity of geological examinations of all dam, pipe line, and bridge sites, should be emphasized. Tremendous damage was done to these kinds of engineering structures in the San Francisco earthquake. It is well known that the breaking of the water mains by the earthquake left the city at the mercy of the fires which shortly broke out.

7. The harbors of Cebu, Iloilo, and Zamboango, owing to their approximating the shape of a funnel or double funnel, are more or less in danger from tidal waves.

8. Manila harbor, owing to the comparatively small entrance and rapidly widening basin, should be quite safe in this respect.

SUMMARY AND CONCLUSIONS

1. There is a close relationship between seismic disturbances and geological structure.

2. The majority of earthquakes are of tectonic origin, in the Philippines at least.

3. Volcanoes are secondary phenomena.

4. The area of greatest seismicity in the Archipelago is in the Agusan Valley, Mindanao.

1. There is a close relationship between seismic disturbances and geomorphic lines and the lines connecting the principal epicenters in the Archipelago.

6. Seismic disturbances can be studied, and disasters can, to a large extent, be avoided.

THE SO-CALLED LUMINOUS PHENOMENA OF EARTHQUAKES, AND THE PRESENT STATE OF THE PROBLEM

By MONTESSUS DE BALLORE,
Director of the Seismologic Service of Chile

In several reports of earthquakes there are described special luminous phenomena which are said to have accompanied them, but it is only of late years that the subject has attracted the attention of scientific men. It seems to be worth while to inquire into the matter, and such is the object of the present paper.

I. Galli's catalogue of luminous phenomena of earthquakes.—Professor Galli has collected in his valuable catalogue all the reports of earthquakes for which such observations have been recorded.¹ He reports 148 seismic movements of this class. He proposes to publish an additional paper on the subject; and if we include those he was not aware of at the time of the first paper, it is probable that we shall obtain a list of two hundred earthquakes characterized by luminous phenomena. It is noteworthy that all of these earthquakes have been more or less destructive. Milne's catalogue of destructive earthquakes² contains a list of 4,136 definite shocks; so if these luminous phenomena are really associated with the earthquakes, they happen only in five per cent. of the great seismic disturbances; in other words, they are very uncommon.

When one reads Galli's list without any preconceived ideas on the subject, he gets the impression that in most cases it is a matter of observation, and of quite unscientific observation at that. The descriptions lack precision, and many of them contain fantastic details. The time-intervals between the earthquakes and the luminous phenomena are very variable, being some seconds, minutes or even hours before or after them. They are reported indifferently from localities of the epicentral area or from very distant ones, and they more frequently come from the atmosphere than from the ground.

¹"Raccolta e classificazione di fenomeni luminosi osservati nei terremoti." *Bollettino della Società Sismologica*, 14, 221, Modena 1910.

²"A catalogue of destructive earthquakes A. D. 7 to A. D. 1899." *British Association for the Advancement of Science*, Portsmouth Meeting, 1911.

It is evident that if such luminous phenomena really do occur, they should comply with the three last conditions included implicitly in the respective critics before alluded to.

I am therefore of the opinion that, in spite of its value, Galli's catalogue does not settle the question.

II. Luminous phenomena in the catalogues of Chinese earthquakes.—Amongst the earthquake catalogues of historic times—not to say of scientific times—the Chinese lists are the ones in which the chroniclers have brought together the greatest number of phenomena—cosmical, meteorological, biological, and illusory—that they assume to associate with the earthquakes they describe. In this connection it is enough to quote Biot's³ and Mouch Ketow-Orlow's⁴ catalogues, for Hoang's⁵ list is much more guarded in this respect. It is very remarkable that in these Chinese seismic catalogues there is not a single report of luminous phenomena accompanying the earthquakes. Indeed the absence of such mention may be said to be quite unaccountable, if such phenomena have any genetic relations to the earthquakes. In spite of its negative character, this is a very strong point against these conjectured luminous phenomena.

Two recent earthquakes, however, afford arguments in favor of the opposite theory.

III. Luminous phenomena accompanying the Chilian earthquake of August 16, 1906.—We have not less than 136 reports of luminous phenomena said to have been observed some time before or some time after the disastrous Chilian earthquake of August 16, 1906. I have already pointed out⁶ that, without distorting the respective texts which I published in extenso in the paper quoted, these reports may be classified as follows: (1) There are forty-four verbal negative reports. (2) There are sixteen implicitly negative reports, for their authors

³Catalogue général des tremblements de terre et soulèvements de montagnes, observés en Chine depuis les temps anciens jusqu'à nos jours. Litteralement traduit du texte original des auteurs Chinois et présenté à l'Académie des Sciences de Paris le 5 Mai, 1839." *Annales de chimie et physique*, Paris 3e Sér. II, 1841, 372.

⁴"Catalogue of earthquakes of the Russian Empire and of adjacent countries." *Memoir Imperial Society of Geography*, St. Petersburg, 1893. (In the Russian language.)

⁵"Catalogue des tremblements de terre observés en Chine." *Extrait du Bulletin de l'Observatoire de Zi-ka-wei*, 33, 1907.

⁶"Fenomeni luminosi speciali che avrebbero accompagnato il terremoto di Valparaiso del 16 de agosto de 1906." *Bollettino della Società Sismologica Italiana*, 16, 77, Modena, 1912.

failed to mention luminous phenomena, although they had been asked about them in a special questionnaire. (3) Thirty-eight reports mention ordinary lightning, without any other phenomena. (4) Thirteen report diffuse lightning, that is to say what is popularly called heat-lightning. (5) Nineteen speak of luminous phenomena in the form of more or less definite aeroliths, bolides or other meteors. (6) One observer reports a fire or phosphorescent light, coming from the soil. (7) Five persons tell of sparks emitted by the touching of telephone wires, of telegraph or of electric-traction line wires in the cities of Santiago and Valparaiso.

But inasmuch as on the night of the earthquake there was a violent rainstorm all over the region, accompanied by thunder and wind, there is no doubt but that these luminous phenomena are to be ascribed to the electric phenomena caused by the storm.

IV. Luminous phenomena accompanying an earthquake in Germany and Switzerland on the night of November 16-17, 1911.—From four valuable papers⁷ I have found records of 112 observations of luminous phenomena that preceded for only some seconds the earthquake of November 16-17, 1911. Most of them came from persons of scanty scientific knowledge. From a paper now in press⁸ I quote the 110 observations reported. As in the preceding case, they can be classified as follows: Twelve persons report explicitly the fall of a meteor or of a bolide; seven tell of falling or shooting stars; twenty-four observers report ordinary lightning, and eight report heat-lightning; forty-three mention diffuse illuminations, that may be ascribed to the same phenomena; there are seven observations of fire-balls, more or less strange. In these last instances we seem to have to do with reports of "feux St. Elme, feux follets, ignis fatuus," or something of the kind.

⁷v. Schmidt und Mack. "Das süddeutsche Erdbeben vom 16 November, 1911." *Württ. Jahrb. für Stad. u. Landesk.*, 1912, H. 1, 96. Stuttgart, 1912.

Mack, "Ueber die bei dem grossen schwabischen Erdbeben von 16 November 1911 beobachteten Lichterscheinungen." *Ges. deutsch. Naturf. u. Aerzte Verh.* 1912. Leipzig, 1913.

Neumann u. Deecke, "Das Erdbeben vom 16 November 1911 in Südbaden." *Mitth. d. grossn. geol. Landesamt.*, 7, 149. Heidelberg, 1912.

Ruetschi, "Das Erdbeben vom 16 November, 1911, am Untersee und die Schollbewegung des Seerückens und die Schienerberges." *Jahresb. u. Mitth. d. Oberrh. geol. Ver.* N. F., 3, 113. Karlsruhe, 1913.

⁸"Acerca de los fenómenos luminosos que han acompañado al semiterremoto de la Suiza y de la Alemania del suroeste, el 16 de Noviembre de 1911." *An. Soc. Chil. Hist. Geogr.*, Santiago, 1913.

These last reports indicate phenomena which may have been produced by the earthquake, for, like the seismic disturbance, they originate in the crust of the earth. Unfortunately these observations were made by laborers or by their wives,—that is, by persons without scientific training,—so that the reporters have added minute fantastic details. These reports cannot be taken seriously. We must, however, exclude all electric phenomena characteristic of stormy weather, for during the night in question the weather was very fine and the sky clear, and the stars were shining brilliantly all over the region shaken by the earthquake.

It now remains only to consider meteors, shooting stars, and the accompanying illumination of the sky. On the night of November 16th there is a shower of shooting stars, whose radiant point is near the star *Mu* of the *Ursa Major*, while the well known shower of the Leonids is not far from this same date. It therefore seems highly probable that the earthquake coincided with a fall of meteors or of shooting stars. This conclusion is much the more plausible and tenable on account of many observers having stated that, many times this same night, the shooting stars were very frequent and particularly brilliant. The earthquake originated not far from Ebingen, a little city of the Rauhe Alb, and the epicentral area extended all around. The luminous phenomena were seen as far as 139 kilometers from Ebingen, a fact which it is impossible to explain if they were a direct effect of the seismic disturbance. On the contrary, a shooting star or a meteor which became incandescent when passing through the highest strata of the atmosphere has been easily observed in localities very distant from Ebingen, and this new argument strengthens my own hypothesis.

Epilogue.—At the present stage of our observations it is not scientific or rational either to affirm or to deny the existence of luminous earthquake phenomena; but all the arguments and facts at our command bear us out in a negative conclusion. Remembering what happened at the time of the Valparaiso and Ebingen earthquakes, I am strongly impelled to apply the old Latin adage: *ab uno disce omnes*. It hardly seems worth while at present to examine the numerous explanations that have been offered for the luminous phenomena that are said to accompany earthquakes; and I think the somewhat disrespectful adjective “so-called” I have used in the title of this brief paper, finds its apology.

EARTHQUAKES IN EAST TENNESSEE

By C. H. GORDON

EARTHQUAKE OF MARCH 28, 1913

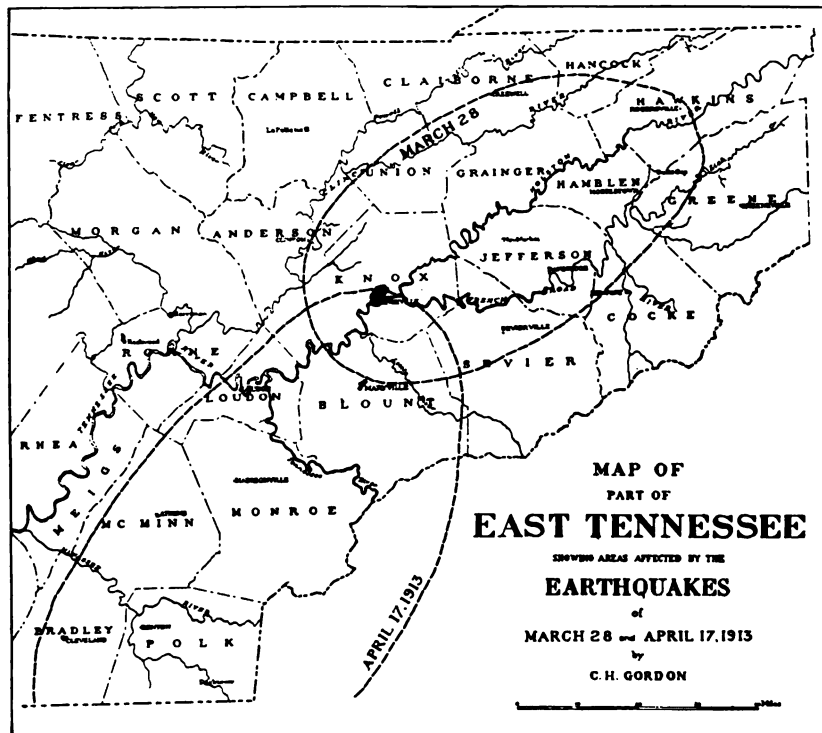
At 4:50 p.m., March 28, 1913, Knoxville and adjoining regions was visited by an earthquake which, though of short duration, was of such intensity as to cause general panic. Some persons report two shocks of about equal intensity, separated by an interval of several minutes. Generally, however, one shock only was recognized, consisting of two distinct concussions separated by an interval of not more than a second.

The shock gave the impression of some violent explosion near at hand, and the occupants of each particular building fled to the street, or sought the boiler-room in the belief that the boiler had exploded. While there were some who recognized that an earthquake had occurred, the general impression was that the disturbance was due to the explosion of a steam-boiler or of dynamite in some of the marble quarries in the vicinity. Finally, when no calamity was reported, and news was received that the shock had been felt over an area having a radius of thirty to fifty miles, the true nature of the disturbance was recognized.

People who were in the open experienced a noticeable rise and fall of the ground, followed by a trembling movement. This was accompanied by a sharp but somewhat muffled report, like distant thunder, ending with a low rumble or roar. Members of the University baseball team who were practicing on the athletic field, and others present there at the time, noted a decided upward and downward movement of the ground, and one stated that he observed the loose sawdust which covers the field thrown upward and slightly toward the northwest, as if the wave movement had come from the southeast. Several persons who were in the sitting-room of the women's dormitory state that a distinct wave-like movement of the floor was felt, coming from the southeast corner of the room and progressing toward the northwest. One young man states that he was lying on the switch trestle of the Louisville and Nashville Railroad near the bank of the

river with his face close to the timbers trying to read the height of the water on the water-gauge, when the shock came with such force as to cause the bridge to strike him on the chin. Accompanying the shock, according to this observer, was a sharp muffled report, which seemed to come from the bluffs on the opposite side of the river and some distance below.

A number of false alarms were rung in at the fire station, apparently due to the vibrations setting off the alarm. In a number of



places bricks were thrown from chimneys, pictures crashed to the floor, and in a few instances furniture was overturned. In a home on Church Avenue a heater was overturned, a potted plant and a table upset, and chairs knocked over. In many homes there was a rattling of dishes and kitchen utensils, and in one a bookcase was overturned.

While the shock was felt in nearly every building in the city,

reports seem to indicate that in no other building was it so distinct as in the Knox County court-house. Observers state that this massive structure, which is situated on the bluff overlooking the Tennessee River, shook and trembled like a leaf for at least three seconds, there being two concussions in quick succession. Persons in street-cars and in automobiles did not experience the shock, and these were greatly puzzled by the general indications of excitement and panic among the people upon the sidewalks whose number were quickly augmented by those who came pouring out of the buildings. A number report a feeling of nausea and sickness, and in some instances indications of fear among horses were noted.

The suddenness of the shock and the sensibly vertical movement experienced by many people suggests that the center of disturbance was in the near vicinity of Knoxville, possibly somewhat to the south-east. From reports received from outside places the area affected was approximately as shown on the accompanying map, with the longer axis lying parallel with the axis of the Great Valley. The shock was not observed at all places within the area outlined, according to reports received; but doubtless a more exhaustive investigation would discover persons who had noted some indication of earth-movement.

Inquiries developed the fact that the earthquake was not recorded by the instruments in any of the seismological laboratories nearest this region, viz, Washington, D. C.; New Orleans, La.; Mobile, Ala.; and St. Louis, Mo.

EARTHQUAKE OF APRIL 17, 1913.

About three weeks later, on April 17th, at 11:30 a.m., a second earthquake was felt over an area somewhat larger than the preceding and lying to the southward. From various places within the area, as outlined on the map, observers report the shock was accompanied by loud noises like deep thunder, the shaking of houses, rattling of loose objects, such as dishes, doors, etc. While there was general agreement in reports of a loud roaring or rumbling noise, the explosive effect experienced in the preceding shock was not noted. A wave-like movement of the ground was reported by a number of observers. Some state that the shock lasted about thirty seconds, but the majority of observers report it as lasting from one to three minutes. In general one shock only was noted; but two observers (Coker Creek, Tenn.,

and Conasauga, Tenn.) report two shocks, separated by an interval of a few seconds only. A quivering or trembling sensation was noted by some, and in a few cases fear and dizziness.

From reports received the shock seems to have been most severe along the axis of the area from the vicinity of Ducktown northward to Kizer, near the Tennessee River. At Knoxville the shock was very slight, and observed by very few persons.

UNIVERSITY OF TENNESSEE.

THE MARVIN STRONG-MOTION SEISMOGRAPH¹

By E. F. DAVIS

The Marvin strong-motion seismograph is an instrument which was designed by Professor C. F. Marvin of the United States Weather Bureau, for the purpose of registering strong earthquakes—earthquakes which would dismantle a more delicate seismograph. A seismograph of this type, constructed according to the original drawings furnished by Professor Marvin, was built at the University of California by Mr. Valdemar Arntzen of the Department of Civil Engineering, the seismograph being completed in the early part of 1911. Upon setting it up it was found to be impossible to get it to work properly on account of certain difficulties which manifested themselves. During the last few months further work has been done on the instrument, some of the parts having been modified considerably.

This paper will attempt, in a rather general way, to describe the seismograph as it was originally constructed; to describe some of the difficulties which were encountered; and then to outline the changes which have been made in the original design, describing the instrument as it now exists.

The mechanism of the Marvin strong-motion seismograph may be considered to consist of three main parts: first, the heavy mass and its supports; second, the recording and damping apparatus; and third, the starting device.

The steady mass of this seismograph is suspended in the form of an inverted pendulum. The arrangement of the pendulum, as it was originally designed, may be seen from Figure 1, which shows a general elevation of the whole pendulum.

The base upon which the pendulum rests is a casting circular in cross-section, and of the form shown in vertical section in Figure 2. (*A*) This casting is firmly embedded in the concrete pier which supports the instrument. Upon the projecting edges of this lower casting there rests an annular casting (*B*), threaded as shown in the figure.

¹ Read at the annual meeting of the Society, April 10, 1913.

Another small casting (*C*) is screwed up from below, and holds a thin disk of tempered steel (*D*) between its upper edge and the projecting rim of the casting (*B*), into which it fits. The disk (*D*) is held in a horizontal position, and is gripped at its extreme outer edge.

Through a perforation in the center of the disk just mentioned, a steel rod (*E*) is inserted and held in place by a nut and washer, as

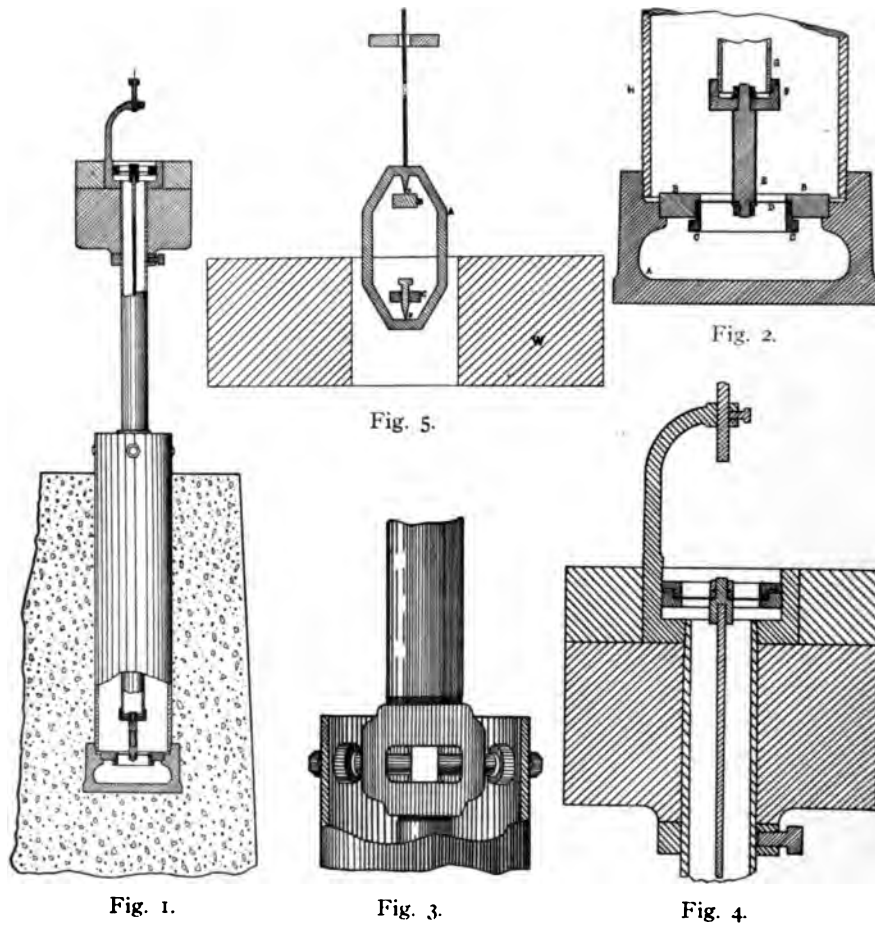


Fig. 1.

Fig. 3.

Fig. 4.

- Figure 1. General Elevation of the Pendulum.
 Figure 2. Details of the Base of the Pendulum.
 Figure 3. Special Casting in Center of Pipe Support.
 Figure 4. Details of the Steady Mass.
 Figure 5. The Starting Device.

shown in the figure. In its normal position—that is, when the supporting disk is not warped—this rod stands in a vertical position. This steel rod (*E*) is inserted and held in place by a nut and washer, as of galvanized wrought-iron pipe (*G*).

At the upper end of this length of pipe there is attached a casting of the form shown in Figure 3. There are three rectangular slots in the sides of this casting, their arrangement being as indicated in the figure. The purpose of this particular casting will become apparent a little later in the description.

As shown in Figure 3, there is another length of wrought-iron pipe above this special casting, and to the upper end of this pipe the steady mass is attached by set-screws, as indicated in Figure 1 and more in detail in Figure 4. The steady mass is circular in cross-section, and an idea of its form may be obtained from the vertical sections shown in the figures. It weighs about 140 pounds, while the total weight of the complete pendulum is about 160 pounds.

The interesting thing about this pendulum, as it was originally designed, is the method used in supporting it. It is apparent that, under the arrangement just described, the weight of the whole pendulum is supported by the thin disk of steel. When the pendulum is in its normal upright position the disk lies perfectly flat, but when the pendulum is displaced to one side the disk must be warped slightly to accommodate the movement of the rod. Theoretically the pendulum, supported in this manner, will have perfect freedom of motion in all directions.

In order to render an inverted pendulum of this kind stable it is necessary to employ a spring of some sort. This is arranged in the following way:

Into the bottom casting there is screwed an outer casing of cast iron, in the manner indicated in Figures 1 and 2 (*H*, Figure 2). This casing completely encloses the lower part of the pendulum and runs up, as shown in Figure 1, until it almost reaches the top of the special casting in the middle of the pipe support. At a short distance below the top of the outer casing three holes are drilled, and in these holes screws are set, as shown in Figure 1 and in detail in Figure 3. These screws pass in through the three slots in the special casting, and the openings are of such size and so arranged that the screws, when in place, do not interfere with the free movement of the pendulum in any

At the center these three screws grip firmly a triangular prism of steel. In the center of this prism a narrow cylindrical steel rod is inserted. This rod runs up vertically through the center of the pipe which supports the steady mass, the lower end being fixed, as described, in rigid connection with the outer casing and therefore with the pier supporting the instrument.

The upper end of this rod is attached to a thin metal disk, in the manner indicated in Figure 4. This upper disk is similar to that employed at the bottom to support the pendulum, and it is rigidly attached to the steady mass, in the manner shown in the figure. Here also the arrangement is such that when the pendulum is in its normal upright position the disk is horizontal. It was intended that when the pendulum was displaced to one side of its upright position, the elastic stresses set up by the bending of this rod would cause the pendulum to return to its original position.

The essential features of the recording device may be mentioned rather briefly. An upright rises from the top of the steady mass, as shown in Figures 1 and 4, and from a point on this upright two arms run out, one in a north-south and the other in an east-west direction. These arms are attached to the writing-points through a system of levers. The damping is provided by vanes which move in chambers filled with oil. The oil chambers are so arranged that the amount of damping may be varied at will or thrown out altogether.

The recording drum, which carries the smoked paper on which the record is written, is about eleven inches in diameter and makes one revolution in three minutes, giving a very open record. Since the recording drum runs so rapidly it would be inconvenient to run it continuously. It is therefore attached to a starting device which sets the drum in motion at the time of beginning of a strong earthquake. With this device it is not necessary to change the records except after an earthquake. The clock driving the drum is wound up and "set," and is connected with the starting mechanism. When the latter is disturbed by an earthquake an electric circuit is closed, which releases the brake on the driving clock. The clock then runs for three minutes—that is, during a complete revolution of the drum. At the end of this time the brake on the driving clock is reset automatically, and the drum stops. If it should happen that the ground were shaking at the end of three minutes the starter would again be set in action and the drum

would continue to revolve for three minutes more. In this way all strong aftershocks would be recorded.

The device used for starting the driving clock is an instrument which was known as the Marvin Seismograph and was described under that title by Professor Marvin in the *Monthly Weather Review* for July, 1895. This instrument was originally designed in order to give an apparatus for obtaining the time of arrival of earthquakes which would be simple and cheap and which would require comparatively little attention.

The essential features of the starter are shown in a general way in Figure 5.

A is a steel link of the form indicated. *B* is a projection of the frame which carries the instrument. At the upper end of the link (*A*) there is a steel point which bears upon the projection (*B*) at the point *x*. The weight or heavy mass of the instrument (*W*) occupies the position shown, and is in the form of a cylinder with a cylindrical opening passing up through its center. *C* is a small bar which runs across the central opening of the steady mass, and is attached to it on both ends. Through the middle of this bar a hole is bored, and through this hole a screw is inserted. The point of this screw bears on the bottom of the steel link at the point *y*, and the whole device is so arranged that the point *y* is slightly above the center of gravity of the weight.

When an earthquake occurs the movement of the frame of the instrument will affect the point at which the link is suspended, carrying it to one side. The weight, however, will tend to remain at rest, and as a result the link will be slightly displaced from its normal vertical position. In order to magnify this motion a long needle is attached to the upper end of the link. The upper end of the needle moves through a considerable amplitude, as compared with the movement of the frame. The upper end of the needle is tipped with platinum, and it passes through a hole in the center of a plate attached to the upper part of the frame carrying the instrument. The hole through which the needle passes is bushed with platinum. If a movement of the ground takes place it will, if sufficiently great, cause the needle to strike the sides of the hole, and by a proper arrangement of wires an electric circuit may be closed at the instant of contact of the needle with the sides of the hole. The starting device is bolted to the pier of the strong-motion seismograph, and everything is so arranged that when the needle strikes

the sides of the hole through which it passes it closes a circuit, which removes the brake from the clock which drives the recording drum.

After the strong-motion seismograph had been constructed according to the ideas which have just been outlined, it was found, upon setting it up and testing it, that the pendulum when displaced did not return directly to its position of rest as it should have done, but moved back and forth in an irregular curve around its original position before coming back to the starting point. Also, the pendulum showed a decided tendency to become unstable.

These difficulties appear to have been due, in part, to the fact that it was impossible to construct the disk at the bottom in such a way that its thickness and elastic properties were equal along all its radii. Since this was not true, the pendulum would not have equal freedom of motion in all directions.

Also the central rod which was used as a spring for supporting the pendulum was attached at the top to a steel disk held rigidly in the steady mass. Upon displacing the pendulum the rod would be bent into a curve, and all changes of length must have been accommodated by the warping of the disk, since the rod was fixed both at the top and the bottom. Under these conditions the elastic stresses set up on bending the rod by displacing the pendulum would be exceedingly complex. One set of these stresses would be due to the flexure of the rod. Another set of stresses would be set up in the disk when it was deformed; and since the elastic properties of such a disk are not equal in all directions, the stresses thus set up would not be the same when the pendulum was displaced in different directions.

Upon modifying the instrument it was decided to abandon the upper and lower disks altogether, and to replace them with other contrivances. No other changes were made in the design. The changes which were made will become apparent from the drawings in Figure 6.

As the seismograph is now constructed, the outer casing (*C*, Figure 6) and the basal casting (*D*, Figure 6) are the same as before. On one end of the pipe which supports the pendulum there is attached, instead of the former coupling, a bronze casting (*E*) of the form indicated in the two vertical sections shown in Figure 6. On the projecting edges of the bottom casting (*D*) there rests a second bronze casting (*F*) of the form indicated. The cross-piece of this second casting is so arranged that it can be removed, being held in place by a couple of screws, as indicated in vertical section, *B-B*. This cross-piece goes

through the central opening of the first casting (*E*), so that when in position the two castings interlock, fitting into each other like two links in a chain. Holes are bored through the centers of the cross-pieces of the two castings, and a steel piano-wire, clamped as shown in the drawings, is passed through the holes. Under this arrangement the whole weight of the pendulum is supported by the tension in the

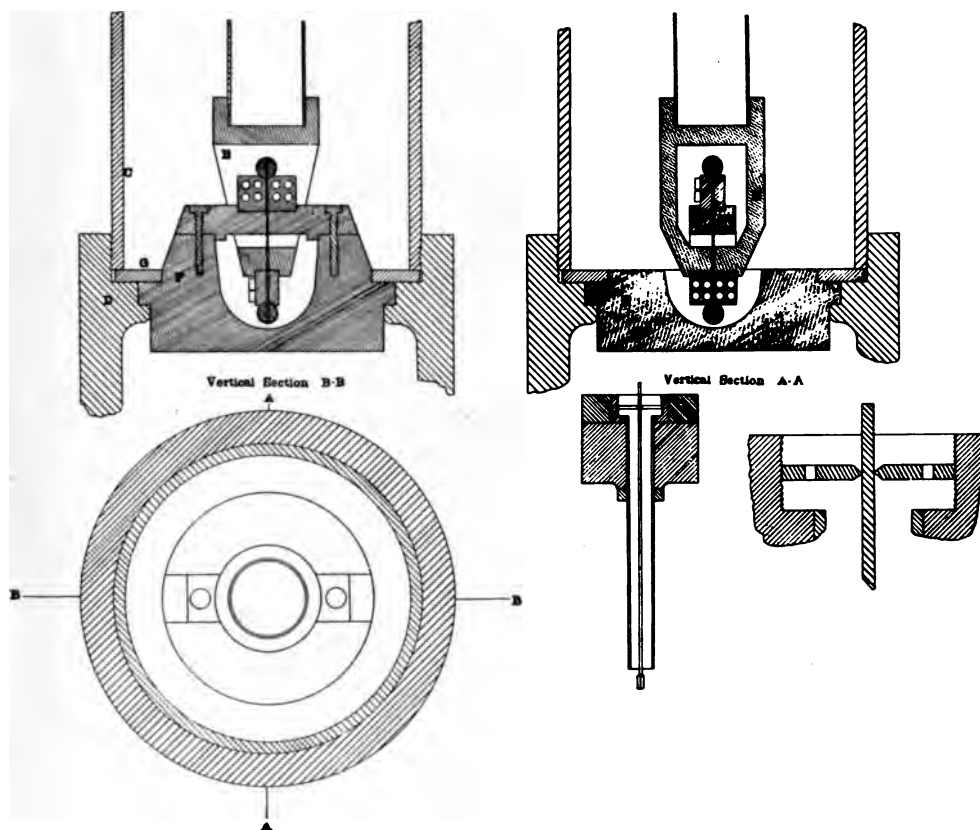


Figure 6. Modifications in the Original Design of the Instrument.

wire. An annular casting (*G*), shown in the drawings, holds the lower casting firmly in place, and is itself held in place by the outer casing, which screws down upon it.

In modifying the rod formerly used for a spring the old castings were removed, and in their place a single plate of tempered steel was

substituted. The general arrangement of this plate is shown in the drawings in the lower right-hand corner of Figure 6. The upright rod passes up through the center of this plate as shown, and the edges of the hole through which it passes are brought down to a knife edge, so that the plate cannot bind the rod but must permit it to slip through, thus allowing for all changes of length required when the pendulum is displaced. The hole is accurately bored, and is of such diameter that it barely permits the rod to move through it without binding. The amount of lost motion is negligible.

With such an arrangement the only stresses set up when the pendulum is displaced are stresses due to the flexure of the rod. When stressed by displacement of the pendulum, the rod brings the pendulum directly back to its original position, the center of gravity of the pendulum moving in the same vertical plane in which it was displaced.

The plate is so arranged that it may be screwed up and down, thus permitting a change in the length of the rod, and a corresponding change in the period of the pendulum. Under the old arrangement no such adjustment was possible.

As it is now constructed the seismograph has a period of six and a half seconds. When the period exceeds seven seconds the instrument does not behave properly, as the pendulum has a tendency to become unstable. The rod in use at present, however, is only an ordinary steel rod, and its elastic properties must be slightly different in different directions. It is believed that with a specially constructed rod, where the elastic properties were more nearly uniform, a much longer period could be secured.

UNIVERSITY OF CALIFORNIA.

SEISMOLOGICAL NOTES

Knoxville, Tennessee.—August 3, 1913, a slight earthquake is reported to have occurred at Knoxville at 11:45 a.m. A rumbling sound was heard, and a slight quiver of the ground was noticeable similar to the shock of last March. The seismographs at Cleveland and Washington did not record any movement.

Earthquake in the Canal Zone.—Two distinct shocks are reported at both Colon and Panama City on the night of October 1, 1913. The seismographs recorded earlier disturbances that were not noticed. The first shock occurred at 11:20 p.m. and lasted for about five seconds. The second and most severe one came at 11:25 p.m., lasting for ten seconds. The movement appeared to be from east to west. Doors were opened, bells rung, and in places furniture moved. The intensity is estimated to have been III to IV.

Later reports indicate that the shocks were felt most severely in the Los Santos province, one hundred and twenty miles from Panama City. Considerable damage is reported in Los Santos city and the surrounding country. Seismographs at Colon indicate that the center of the disturbance was some distance north of the city in the Caribbean sea.

On October 3rd, Washington officials received word from Panama stating "Earthquake caused no damage to any canal structures, nor did it create or increase any old slides."

Another shock in the Canal Zone.—A severe earthquake was felt on the Isthmus at 5:06 p.m., October 4, 1913. It was equal in intensity to the shocks of October 1st, its duration being from ten to fifteen seconds.

Earthquake near Naples.—On October 4, 1913, a strong shock occurred at 7:20 p.m., and a less severe one at 7:30 p.m., according to reports. The first shock lasted thirty seconds, and had an undulatory motion.

Panama earthquake.—An unconfirmed report from Panama City states that the village of Tonosi in the western part of the republic was destroyed by an earthquake October 6, 1913. Tonosi is a village of about three hundred inhabitants.

Alcutian Islands.—Vessels arriving from the vicinity of the Aleutian Islands report many volcanoes in active eruption. Ashes have fallen far out at sea, and covered the surface of surrounding islands to a depth of several inches.

Messina, Sicily.—On October 9, 1913, a strong earthquake is reported to have occurred at Messina, in the daytime, lasting twelve seconds. It caused considerable panic, but little or no damage.

Canal Zone.—A slight shock was felt at Colon at 7:50 p.m. October 11, 1913.

Eastern Oregon.—A rather severe earthquake is reported to have occurred at 3 p.m. October 14, 1913, in the Seven Devils district along the Idaho-Oregon line. Reports state that the shock lasted one minute, shook houses, and broke windows and dishes.

Stirling, Illinois.—A report states that a slight earthquake was felt at Stirling at 8:15 p.m. October 16, 1913, lasting about ten seconds.

Panama.—October 16, 1913. Recent reports indicate the center of the recent earthquake disturbances as being some distance off the coast from the town of Tonosi in Los Santos province. Cable repair ships report a marked increase in depth fifteen miles off the coast.

Nicaragua.—Violent earthquakes are reported from the towns of Managera, Masaya, and Granada, October 17, 1913. One building collapsed near Granada. Disturbance still continues at Granada.

Canal Zone.—Another earthquake is reported from both Colon and Panama City at 10:01 a.m. October 23, 1913, lasting twenty to twenty-five seconds in two slightly separated periods. Estimated intensity IV +. Ancon seismograph recorded northeast-southwest movement, so severe as to throw the pen off the paper. Unconfirmed reports from Los Santos province indicate that shocks were very severe there.

Stanford University, California.—An earthquake was felt here October 25, 1913, about 1:45 a.m.; intensity about IV. It was felt in Palo Alto (Standard time, P. S. T. 12 h. 41 m. 45 s. a.m.). This shock seems to have been felt slightly at Ross, Marin county. At Oakland, California, reports indicate two shocks of six to eight seconds duration; intensity II; time early a.m.

Messina, Sicily.—A severe earthquake is reported to have occurred near Messina, November 8, 1913. It was followed by two shocks of less severity. No damage is reported.

Lima, Peru.—November 11, 1913: Reports of a violent earthquake in the Abancay province on November 7, 1913, have been confirmed. The reports state that the city of Challhuanca was wrecked and two hundred persons killed; ten towns are in ruins, and the people are living in the open country. Abancay or Aymareas is in the department of Apurimac. Aid has been requested from the government at Lima, and a large quantity of provisions is being forwarded to the refugees.

Lima, Peru.—November 13, 1913: Reports from the province of Aymareas state that two hundred and fifty bodies have been taken from the ruins of Challhuanca, one of the ten towns destroyed by the earthquake of November 7th. Challhuanca, the capital of Aymareas, lies about two hundred and fifty miles east-southeast of Lima, and, so far as known, has been free from disastrous earthquakes in the past.

Messina, Sicily.—An earthquake is reported to have occurred at Messina November 16, 1913, at about 2 p.m.

No damage from earthquakes at the Panama Canal.—November 16, 1913: Dr. Krause, the builder of the re-enforced concrete dry-dock that went through the Valparaiso earthquake unscathed, after inspecting the canal, stated that none of the canal structures are in danger of damage by earthquake.

Another slight shock was felt upon the Isthmus at 6:50 a.m., November 13, 1913. It lasted five seconds, and was the first pronounced disturbance in two weeks. It appears that the period of greatest disturbance is past, as the shocks are growing less severe and less frequent.

Stanford University, California.—A slight earthquake was felt here at 5 a.m. November 20, 1913. Intensity III +.

Eureka, California.—A distinct earthquake was reported from the towns near Eureka and Fort Seward at 7:50 p.m., November 24, 1913. The earth movement was pronounced, but no damage is reported.

Lima, Peru.—Another violent earthquake is reported to have occurred December 4, 1913, in the vicinity of Challhuanca, capital of the province of Aymareas, the scene of the disastrous shocks of a month ago.

Professor Milne.—At the meeting of Section 4 of the British Association at Birmingham, Professor H. H. Turner presented the report of the Seismological Committee, which report was drawn up by Professor Milne just before his death. In considering what steps should be taken to carry on Professor Milne's work, it was decided to try and obtain sufficient funds to enable the observational work to go on. Professor Turner has undertaken to exercise a general supervision over the station at Shide. For the present this seems a satisfactory management, but it is unfortunate that the work cannot be carried on with proper equipment and personnel.—*Nature*, November 6, 1913, p. 309.

REVIEWS.

THE JOURNAL OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA.
May-June, 1913.

At page 229 of *The Journal of the Royal Astronomical Society of Canada*, under the head of "Location of Epicenters for 1912." Dr. Otto Klotz gives a continuation of the epicenters located in 1911. The method used in locating the epicenters has been described by Dr. Klotz in this BULLETIN, 1, 143.

Forty-seven earthquakes are tabulated in this report, and many of the epicenters determined are compared with results obtained by Prince Galitzin and Professor Zeissig. From June 7-10 seven epicenters were located in latitude 57° to 59° north and longitude 143° to 161° west. June 7th was the date of the violent eruption of Mount Katmai, in Alaska. Dr. Klotz gives in addition a discussion of the various sources of error affecting the determination of epicenters by his method.

S. D. T.

NOTE ON RECENT EARTHQUAKE IN CAPE BRETON. By D. S. McIntosh. *Proceedings and Transactions of the Nova Scotian Institute of Science*, 12, Part IV, 311-312. Halifax, 1913.

A local earthquake was felt in a part of Inverness county, Cape Breton, Nova Scotia, Canada, on December 20, 1909, at 3 p.m. The shock lasted five seconds; intensity, as estimated from the descriptions, reached VI of the Rossi-Forel scale and was preceded by a rumbling noise. The area affected was small. A collapse of a cave or other local disturbance in the Carboniferous limestones is suggested as the cause of the shock.

C. F. TOLMAN, JR.

RESULTS OF OBSERVATIONS MADE AT THE UNITED STATES COAST AND GEODETIC SURVEY MAGNETIC OBSERVATORY NEAR HONOLULU, HAWAII, 1911-1912. By Daniel L. Hazard.

The tables of the various series of meteorological and magnetic observations carried on by the Coast and Geodetic Survey Magnetic

Laboratory, Hawaii, include the shocks registered on the Milne Seismograph. Three hundred and fourteen tremors are listed during the years 1911 and 1912, and all the data usually included in such tables are given.

C. F. TOLMAN, JR.

TEMBLOR EN CATALUNA, ESPANA. *Revista de la Sociedad Astronomica de Espana y America*, Ano 3, Num. 23, p. 36, Febrero de 1913.

This includes a short account of the earthquake of November 22, 1912, which affected the coastal region of Spain northeast of Barcelona. The article contains a sketch map of the region on which the isoseismal lines are located. The latter are ellipses parallel to the coast and the mountain ranges. The maximum intensity was VI, Rossi-Forrel scale, and the depth of the center is estimated between 1500 and 2000 meters.

C. F. TOLMAN, JR.

LOS FENÓMENOS SISMICOS. Por A. Cañas Pinochet. Brevisima exposición del estado en que se encuentra el estudio de los fenómeno, y extractada de unas conferencias dadas por el autor en la *Sociedad Chilena de Historia y Geografía*. Santiago de Chile, imprenta universitaria, Bandera, 130, 1912.

In this pamphlet of twenty-one pages, Senor Pinochet lists and describes briefly the more important earthquakes that have affected Tarapaca, Peru, and gives in somewhat more detail an account of the earthquakes of August 13, 1866, and May 9, 1877. The earthquakes described include those of February 8, 1570, December 16, 1575, May 13, 1687, July 8, 1730, May 25, 1751, one in 1822, February 20, 1835, and August 16, 1906.

Destructive tidal waves are mentioned as accompanying those of 1520, 1575, 1751, 1868, and 1877. During the earthquake of 1575 an embankment was formed across the river Calle-Calle, through which the water forced a passage a few days later, drowning 1200 Indians. The earthquake of 1822 is stated to have elevated the coast about one meter.

The paper is closed by a summary of some of the modern ideas regarding the cause and distribution of earthquakes.

C. F. TOLMAN.

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS OF
THE SEISMOLOGICAL SOCIETY OF AMERICA,
DECEMBER 15, 1913.

The meeting was called to order by the secretary at 3:30 p.m., in Room 111, Leland Stanford Jr. University, Stanford University, Cal. Dr. Branner was asked to act as chairman. Directors Branner and Townley were present and Directors Bauer, Burckhalter, von Geldern, Marvin and Reid were represented by proxies.

The minutes of the meeting of the Board of Directors held on April 10, 1913, were approved as printed on page 97 of this volume of the BULLETIN.

Fourteen new members, whose names are subjoined hereto, were recommended and duly elected to membership in the Society. Three institutions were placed upon the list of subscribers to the BULLETIN.

The secretary reported the death of Professor C. G. Rockwood, a member of the Society.

A nominating committee and a board of election were appointed as follows:

NOMINATING COMMITTEE	BOARD OF ELECTION
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B. A. Baird,	E. F. Davis,
H. L. Haehl,	W. F. Martin,
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W. G. Reed.	H. W. Turner.
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December 15, 1913

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- I. Microseismic shock:** recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.
- II. Extremely feeble shock:** recorded by several seismographs of different kinds; felt by a small number of persons at rest. some startled persons leave their dwellings.
- III. Very feeble shock:** felt by several persons at rest; strong enough for the direction or duration to be appreciable.
- IV. Feeble shock:** felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.
- V. Shock of moderate intensity:** felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.
- VI. Fairly strong shock:** general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stop-
- VII. Strong shock:** overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.
- VIII. Very strong shock:** fall of chimneys, cracks in walls of buildings.
- IX. Extremely strong shock:** partial or total destruction of some buildings.
- X. Shock of extreme intensity:** great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

INDEX TO VOLUME III.

	PAGE
Agamennone, G.—Il disastroso terremoto nel Bacino occidental del Mar di Marmara (review)	93
Il servizio sismico in Grecia, nei Balcani e nell' Impero Ottomano (review)	94
Il terremoto del 24 Gennaio, 1912, nelle Isole Jonie e sua velocita di propagazione (review)	94
Allen, C. G.—Reviews of three papers by Agamennone.....	93, 94
Ballore, Montessus de—The so-called luminous phenomena of earthquakes and the present state of the problem.....	187
Branner, J. C.—Earthquakes and structural engineering.....	I
On the earthquake of January 2, 1912, in the Upper Mississippi Valley (review).....	40
The Mexican earthquake of June 7, 1911 (review).....	42
Études sur la séisme du Ribatejo du 23 Avril, 1909 (review)	148
Bulletin semestriel de l'observatoire météorologique du Séminaire-College St. Martial, Port-au-Prince, Haiti (review)	149
Campbell, Leon.—Earthquakes at Arequipa, Peru.....	83
Coast and Geodetic Survey, Bulletin of the (review).....	148
Colima in eruption (note).....	34
Davis, E. F.—Beitrag zur Bestimmung der Fortpflanzungs- geschwindigkeit der Erdbebenwellen in den obersten Erd- schichten (review)	43
The registration of earthquakes at the Berkeley Station and at the Lick Observatory Station from April 1 to September 30, 1912	146
The Marvin strong-motion seismograph.....	195
Davison, Charles—The origin of earthquakes (review).....	143
Denison, F. Napier—The horizontal pendulum in relation to cer- tain phenomena	104
Earthquake of January 1, 1913, the South Carolina, by Stephen Taber	6
Earthquake at Westport, New Zealand, by P. G. Morgan.....	121
Earthquakes and structural engineering, by J. C. Branner.....	I

Earthquakes and rainfall, by R. W. Sayles.....	51
Earthquakes at Arequipa, Peru, by Leon Campbell.....	83
Earthquakes in South Africa, on the occurrence of, by H. E. Wood	113
Earthquakes in East Tennessee, by C. H. Gordon.....	191
Earthquakes in Buckingham County, Virginia, by Stephen Taber	124
Earthquakes, the origin of, by Charles Davison (review).....	143
Earthquakes at the Berkeley Station and at the Lick Observatory Station from April 1 to September 30, 1912, the registration of (review)	146
Earthquakes, notes and reviews concerning:—	
Aleutian Islands	204
Ann Arbor, Mich., registration of.....	39
Azores	34, 86
Canal Zone	203, 204, 205
Cape Breton	207
Cataluna, Spain	208
Constantinople	35
Equador	35
Eureka, Cal.	206
Guatemala	35, 86
Hamburg, Germany, registration of.....	42
Honolulu	207
Idaho	204
Ionian Islands	94
Kilauea	86
Kingston, Jamaica	141
Knoxville, Tenn.....	140, 203
Lima, Peru	205, 206
Marmora	93
Medford, Ore.	35
Messina, Sicily	88, 141, 142, 204, 205
Mexico	41, 42, 86, 149
Mt. Rainier, Wash.	142
Naples, Italy	203
New York	88, 139
New Zealand	36
Nicaragua	141, 204
Oregon	204

Earthquakes, notes and reviews concerning:—

Ottawa, Canada	138
Panama	203, 204, 205
Philippine Islands	138
Point Loma, Cal.	138
Port-au-Prince, Haiti	149
Portugal	148
Rome, Italy	139, 140
St. Louis, Mo.	138
Salt Lake City, Utah.....	87
San Bernardino, Cal.	87
San Jose, Cal.	140
Santa Clara, Cal.	139
Sofia, Bulgaria	140
Sorsogon	144
Stanford University, Cal.	205, 206
Stirling, Ill.	204
Tarapaca, Peru.....	208
Tennessee	85, 87, 203
Upper Mississippi Valley	40
Venezuela	34
Washington, D. C.	87
Election committee, report of	98
Epicenter, determination of the, by B. Galitzin and G. W. Walker	37
Galitzin, B. (with G. W. Walker)—Determination of the epicenter	37
Ueber eine dynamische Skala zur Schätzung von Makroseismischen Bewegungen (review)	90
Gordon, C. H.—Earthquakes in East Tennessee	191
Hausmann, K.—Beitrag zur Bestimmung der Fortpflanzungsgeschwindigkeit der Erdbebenwellen in den obersten Erdschichten (review)	43
Hawaiian Volcano Observatory, the, by H. O. Wood.....	14
Hazard, D. L.—Results of observations made at the U. S. Coast and Geodetic Survey Magnetic Observatory near Honolulu (review)	207
Hirota, Shinobu, returns to Japan, by J. Milne.....	37
Horizontal Pendulum in relation to certain phenomena, the, by F. Napier Denison	104

Klotz, Otto—The undagraph	20
Kolar Gold Field, Mysore, India, air-blasts and shocks in the gold mines of the, by J. B. Woodworth.....	80
Luminous phenomena of earthquakes and the present state of the problem, the so-called, by Montessus de Ballore.....	187
McAdie, A.—Volcanoes and climate (review)	89
The Sorsogon earthquake (review)	144
McIntosh, D. S.—Note on recent earthquake in Cape Breton....	207
Masó, M. S.—The new seismic station near Taal volcano.....	49
The Sorsogon earthquake	144
(with W. D. Smith) The relation of seismic disturbances in the Philippines to the geologic structure.....	151
Members of the Seismological Society	210
Milne, J.—Shinobu Hirota returns to Japan	38
Account of life and work, by J. W. J.	134
Note concerning work	206
Missouri, the New Madrid and other earthquakes of.....	57
Mitchell, W. M.—The registration of earthquakes at the Detroit Observatory from August 16, 1909, to January 1, 1912 (review)	39
Morgan, P. G.—Earthquake at Westport, New Zealand.....	121
New Zealand earthquake at Westport, by P. G. Morgan.....	121
Peru, earthquakes at Arequipa, by Leon Campbell.....	83
Philippines, the relation of the seismic disturbances in the Philip- pines to the geologic structure, by W. D. Smith and M. S. Masó	151
Publications received	46, 96
Reid, H. F.—Determination of the constants of a seismograph..	24
Sudden earth-movements in Sumatra in 1892.....	72
Report of secretary-treasurer	99
Reviews of seismological publications.....	39, 89, 143, 207
Rogers, F. J.—Die seismischen Registrierungen in Hamburg (review)	42
Rossi-Forel scale	48, 102, 150, 220
Royal astronomical journal of Canada, the journal of the, May-June 1913 (review)	207
Sampson, F. A.—The New Madrid and other earthquakes of Missouri	57
Sayles, R. W.—Earthquakes and rainfall	51

Seismograph, determination of the constants of, by H. F. Reid..	24
Seismograph, a suggested improvement of the.....	36
Seismograph, the Marvin strong-motion, by E. F. Davis.....	195
Seismological notes	34, 86, 138, 203
Seismological Society of America:—	
Members of	210
Minutes of meeting of Board of Directors, Feb. 4, 1913..	47
" " " " April 10, 1913	97
" " " " Dec. 15, 1913	209
" " Society April 10, 1913	101
New members and subscribers elected	47, 101, 209
Report of election committee	98
Report of secretary-treasurer.....	99
Smith, W. D. (with M. S. Masó)—The relation of seismic dis-	
turbances in the Philippines to the geologic structure.....	151
South Carolina earthquake of January 1, 1913, the, by Stephen	
Taber	6
Sumatra, sudden earth-movements in, in 1892, by H. F. Reid....	72
Taal volcano, the new seismic station near, by M. S. Masó.....	49
Taber, Stephen—The South Carolina earthquake of January 1,	
1913	6
Earthquakes in Buckingham County, Virginia	124
Tams, E.—Die seismischen Registrierungen in Hamburg, vom	
1 Januar 1910 bis zum 31 Dezember 1911 (review).....	42
Tennessee, earthquakes in East, by C. H. Gordon.....	191
Tolman, C. F., Jr.—The registration of earthquakes at the Detroit	
Observatory from August 16, 1909 to January 1, 1912	
(review)	39
Catalogo de los temblores sentidos en la Republica Mexicana,	
etc. (review)	41
Note on recent earthquake in Cape Breton (review).....	207
Result of observations made at the U. S. Coast and Geodetic	
Survey magnetic observatory near Honolulu (review)...	207
Temblor en Cataluna Espana (review).....	208
Los Fenómenos Sismicos (review).....	208
Townley, S. D.—The origin of earthquakes (review).....	143
The Journal of the Royal Astronomical Society of Canada,	
May-June 1913 (review)	207
Minutes of meeting of Board of Directors.....	47, 97, 209

Townley, S. D.—Minutes of meeting of Society.....	101
Report of secretary-treasurer	99
Udden, A. D.—On the earthquake of January 2, 1912 in the Upper Mississippi Valley (review)	40
Undagraph, the, by Otto Klotz.....	20
Victoria, a new station at (note)	35
Virginia, earthquakes in Buckingham County, by Stephen Taber	124
Volcanoes and climate (review)	89
Walker, G. W. (with B. Galitzin)—Determination of the epicenter	37
Wood, H. E.—On the occurrence of earthquakes in South Africa	113
Wood, H. O.—The Hawaiian volcano observatory.....	14
Ueber eine dynamische Skala zur Schätzung von Makroseis- mischen Bewegungen (review)	90
Woodworth, J. B.—Air-blasts and shocks in the gold mines of the Kolar gold fields, Mysore, India.....	80

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